THE GEOLOGY AND PETROLOGY OF THE GREAT SERPENTINE BELT OF NEW SOUTH WALES.

Part v. The Geology of the Tamworth District.

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(Plates xlix.-liii.; and fifteen Text-figures.)

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Introduction and previous Literature.

Tamworth, now a prosperous town of more than nine thousand inhabitants, is one of the old country-towns of the State. It lies on the Peel River at the foot of the Moonbi Ranges, almost due north of Sydney, and at a distance therefrom by rail of two

hundred and eighty-two miles. Though small amounts of gold and copper have been discovered in the neighbourhood, it has never been in any way a mining centre, and its prosperity has been due to its pastoral and agricultural industries. In this respect, the district falls into three divisions: the hilly north-eastern part, composed of granite and slaty rocks; the gently undulating south-western part, chiefly made up of clayslates; and the wide flood-plains of the Peel and Cockburn Rivers that intersect the district. The first two of these divisions were devoted to sheep- and cattle-raising, and to a small amount of dairying, but now, much of the second division, and the flatter portions of the first, are devoted to the cultivation of wheat. The deep alluvium on the flood-plain produces abundant crops of lucerne.

The district first attracted the attention of geologists when the Rev. W. B. Clarke passed through it in 1852, on his way to investigate the gold-fields of Barraba and Bingara. He noted the large masses of limestone on Moore Creek, to the north of the district, and compared them with the Devonian limestones in the Murrumbidgee valley(**1**). His collections of fossils were described by Professor De Koninck of Liège(**2**), whose results, first published in 1876-7(**2**), were translated into English, and appeared as a Memoir of the Geological Survey of New South Wales(**3**). He described five species of corals as coming from Moara or Mowara Creek, north of Tamworth. A little doubt has arisen as to the spot indicated by this name(**11**), but there seems no reason to think it other than what is now termed Moore Creek. In his reports, Clarke rendered the original name of the stream by the spelling "Moura" or "Mouara," and an old map shows the name "Mooar."

Very little geological work was done in the district for the next forty years, though collections were made by Mr. D. A. Porter, of Tamworth, of the minerals and fossils of the district, among which he found hyalite occurring with chromite at Moonbi(**4**), and a new species of coral, described by Mr. R. Etheridge, Jun., as *Diphyphyllum porteri*, in the limestone in the Tamworth Common(**5**).

In 1893, in an address to this Society, Prof. David suggested that the jasperoid slates of the Bingara, Barraba, and Nundle District, which pass through the eastern portion of the area now under discussion, may be altered abyssal deposits(6). Three years later, he discovered that, not only do the jasperoid rocks contain numerous spherical casts, probably replacing radiolaria, but there is a large development at Tamworth of claystones and cherts, and siliceous limestones, containing abundant radiolarian remains, which he briefly described(7). He stated that there appeared to be two beds of coral limestone, one of which was greatly altered by the metamorphosing effect of the New England granite. The thickness of the limestone he placed between 100 and 1000 feet, and added four more forms to the list of fossils. He further remarked: "The claystones and cherty rocks, both above and below the limestone, have also been much altered by innumerable granite sills for a zone over five miles in width measured at right angles to the junction line between the sedimentary rocks and the granite. . . . The sills vary from a fraction of an inch up to several feet in thickness, and at first sight have every appearance of being regularly interstratified with the sediments. A careful examination, however, at once revealed their intrusive character, as they trespass slightly across the planes of bedding, and have slightly altered . . . the sedimentary rocks both above and below them." In another paper he said: "The whole zone for several thousands of feet is half sill, half sediment."(8) So far, however, these apparently intrusive rocks do not appear to have been subjected to microscopical examination.

In 1899 appeared the classical paper on this district, namely, the account given by Professor David and Mr. Pittman conjointly(9). With this there is a geological map of the area. The authors showed that there is an anticline in the valley of Seven Mile Creek, east of the town, and adjacent to the boundary of the granite. Metamorphosed limestone occurs on either side of the axis. Above this, there continues a series of radiolarian cherts, claystones, and lenticular patches of limestone, interspersed with igneous rock. This dips steadily to the west,

and a thickness of 9,260 feet is stated to occur between the anticlinal axis and Spring Creek in the Tamworth Common. Here is a great fault, east of which the limestones appeared again, followed by more radiolarian sediments and interstratified igneous rocks. This limestone is shown to be on the same horizon as that at Moore Creek, and is believed to be also the equivalent of the limestone in Seven Mile Creek. The microscopical examination of the igneous rocks made by Mr. Card having revealed their clastic nature, they are now stated to be felsitic tuffs, but it is still held that they are often intrusive or crushed into the sediments, and pictorial evidence of this is given. The new view, however, removed them from any direct relation with the Moonbi granites. While formerly *Lepidodendron* was found only above the radiolarian rocks, it was now shown to occur within them. On the grounds of the association of the radiolarian chert with coral limestones, the absence of coarse terriginous sediments, the abundance of plant-remains, and the presence of ripple-marking, it was concluded that the radiolarian rocks "were deposited in clear sea-water, which, though sufficiently far from land to be beyond the reach of any but the finest sediment, was nevertheless probably of not very considerable depth." Finally, they discovered certain coarse agglomerates on the hills to the north of Tamworth, which they considered to be unconformable on the clayslates, and probably the basal beds of the Carboniferous System.

The radiolaria in these rocks were investigated by Dr. Hinde, who described fifty-three species, all new to science(**10**). This does not exhaust the radiolarian fauna of the district, however, for additional forms, not yet described, have been noted by Professor David and Dr. Jensen.*

The fossils in the limestones at Moore Creek, Tamworth, and Moonbi, collected by Messrs. David, Pittman, Porter, Beedle, and Etheridge, were described by the last-named, who found nineteen species of corals to be present, most of which were new to science. He considered that the limestone of Moore Creek

* Verbal communication.

and Tamworth lay on the same horizon, and that at Moonbi was rather older, though all might be classed as of Middle Devonian age(11).

On account of the lithological nature of the granite at Moonbi, and the characteristic topography of the areas occupied by that rock, Mr. E. C. Andrews concluded that it was the equivalent of the sphene-granite-porphyry of northern New England, which invades Permo-Carboniferous sediments, and is presumably of early Mesozoic age(12).

A beautiful illustration of the red "marble" of Nemingha has been published by the Technological Museum, and notes made thereon by Mr. Laseron(13).

In the first part of the present series of papers, the writer stated that the Moonbi limestone was on the same horizon as that at Seven Mile Creek, and accepted the view of Messrs. David and Pittman, that the latter was the faulted equivalent of the Tamworth and Moore Creek limestones. He doubted the unconformity between the agglomerates of Cleary's Hill, north of Tamworth, and the underlying claystones, and considered that the former was the equivalent of the Baldwin Agglomerates, and formed the lower part of the Upper Devonian system, which lay conformably on the Middle Devonian rocks. In addition, it was suggested that there was a strong fault running approximately in the valley of the Peel and Cockburn Rivers(14).

This divergence in the conclusions drawn from palæontological and stratigraphical evidence as to the correlation of the limestones, and the different interpretation placed on the agglomerates, were clearly matters calling for investigation. Moreover, it seemed possible that, by detailed mapping, horizons of reference might be discovered, by which the tectonics of the district might be worked out, and a closer approximation made to the true thickness of the formations present, than was formerly possible. There were also the problems of the conditions for the deposition of radiolarian sediments, and the mode of origin of the "intrusive tuffs."

The area studied stretches along the northern side of the Peel River from Moore Creek to Nemingha Creek, a distance of

seventeen miles, and, with a small area south of the river, it comprises eighty square miles, including the Parishes of Woolomol, Tamworth, and Nemingha, and portions of the Parishes of Moonbi and Calala. A topographical and geological map of this was prepared by a survey with a plane-table, and contour-lines were drawn thereon at intervals of two hundred feet, determined by aneroid-readings. The datum-points were the railway stations of Tamworth, Nemingha, Tintinhull, and Moonbi (now renamed Kootingal), which are respectively 1279, 1351, 1330, and 1381 feet above sea-level. The results of the geological and petrological work, and of the determinations by Mr. Dun of fossils collected, are here presented; the physiography will be discussed in another communication.

The result of the work, as will appear, has been to confirm the main points of the views held by Messrs. David and Pittman, though some modification of the details has been found necessary. It seems fitting to acknowledge here the generous help of the officers of the State Geological Survey, and the writer's constant indebtedness to Professor David for advice and encouragement, both in the laboratory and in the field.

General Geology and Tectonics.

The result of the present examination shows that the fourfold subdivision of the Devonian system, formerly proposed by the writer, holds good for the Tamworth district, though the definitions of the several sections need some modification, and it has seemed best to unite the two upper divisions, and to subdivide the large Middle Devonian series below these. On the other hand, it has been found that the subdivision of the Middle Devonian series, deduced from the study of the Nundle district(**15**), does not hold good here, for the reason previously suggested, namely, that the structure of the Nundle district is so complicated by strike-faulting that the apparent succession is probably not the true one. This appears very clearly from the structure of the Parish of Nemingha, which is in a position tectonically similar to that of the Nundle district. The succession in the less disturbed areas of the Parish of Tamworth is

probably much nearer to the true stratigraphical succession, though even here are faults, the extent of which cannot yet be determined, which render all estimates of relative thickness of strata very unreliable. The absence of many good horizons, and the lateral variation of some of the formations are additional causes for uncertainty. On this account, we can no longer accept, as final criteria, the distinctions previously made between the cherts of the Tamworth Series and the mudstones of the Barraba Series, or between the pyroclastic rocks of the Barraba and Tamworth Series and the Baldwin Agglomerates. In spite of this, however, the general facies of a series of associated rocks is usually conclusive. It has been found necessary to separate the limestones of Moore Creek and Tamworth from those in the Moonbi (Nemingha) district, the stratigraphical evidence confirming Mr. Etheridge's conclusion, drawn from palæontological evidence, that the latter were on a lower horizon. There is reason to believe in the occurrence of a third limestone-horizon, the relation of which to the limestone of Moore Creek is not yet obvious. The three limestone-horizons have been termed the Nemingha, Moore Creek, and Loomberah horizons respectively. The last-named is as yet but little known, and its description is reserved until the study of the Parish of Loomberah is made. The several divisions of the formations developed will now be discussed in chronological order.

1. *The Eastern Series, partly of Lower Devonian age.*

It has been assumed in previous papers, that the rocks east of the serpentine, comprising jaspers, and phyllites, are largely of Lower Devonian age, and, to the Lower Devonian rocks proper, the name Woolomin Series has been applied. Unfortunately, they are so intensely folded and faulted, and have thrust in among them so much that seems to be derived from the Middle or even Upper Devonian Series, that it has not seemed worth while, at present, to attempt to disentangle the Woolomin Series from the others, if such a series should really exist. The whole complex, therefore, will be considered together under the term Eastern Series. The following discussion refers only

to the nature and distribution of the several types of rocks developed.

One of the most striking features is the presence of a large amount of basic rock. This forms long intercalations scattered throughout the Eastern Series as shown (diagrammatically) on the Map (Plate l.). These consist of tuffs, breccias, and spilitic rocks, many of which, though more or less altered, are very similar to rocks occurring in the Middle Devonian Series. In the neighbourhood of the granite, they have been changed, into amphibolites, the zone of metamorphism extending from half a mile to a mile from the granite. This amphibolite occurs, for instance, in the north-eastern corner of the Parish of Nemingha, intercalated with mica-schist, and other masses run southwards through portion 155. Where the basic rocks cross the creek in portions 147 and 190, they form several narrow bands of spilite interstratified with jasper and chert. There is no clear evidence of pillow-structure, but some suggestion of it. South of this, spilite crosses Spring Creek as a thick band, partly schistose, partly massive, with some trace of pillow-structure. It is intersected by bands of jasper, and interstratified with highly crushed banded cherts, and with tuff-breccias like those of the Middle Devonian Series.

South of the watershed of Spring Creek, is a sharp hill, marked by a thicket of pine-trees. Here the rock is quite different, partly a tuff-breccia, partly a rather devitrified flow-breccia, of which the brown glass contains crystals of quartz and altered felspar, and pseudomorphs after felspar-augite. This zone of tuff-breccia is of great width, and is interstratified with cherts. It extends southwards across Oakey and Nemingha Creeks, in the beds of which it is well exposed. Many masses of spilite occur with some approach toward a pillowy structure, and intersected by abundant veins of secondary chert. The basic breccia is cemented into a uniformly resistant rock, which makes bold rounded outcrops.

A very perplexing hill is that east of the northern end of the serpentine-belt. At its western base is a large mass of altered basic rock, probably of Middle Devonian age. Above these are

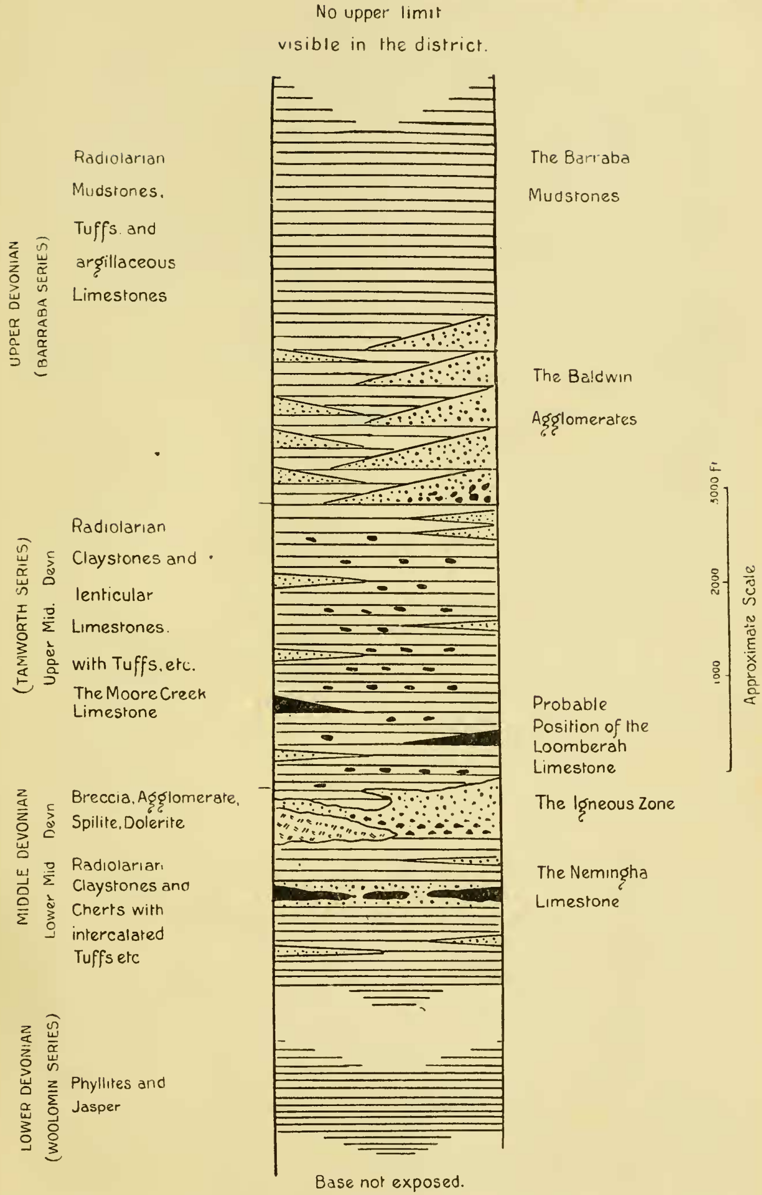
fine grey rocks of quartzitic appearance, and greener masses, like altered tuffs and greywackes. Higher up, the quartzitic rock becomes more coarsely granular, and contains scattered crystals of felspar, and it is intersected by an occasional vein of jasper. The microscope reveals that the greenish rocks are highly altered silicified and strained tuffs, while the rocks of a quartzitic appearance are chiefly much crushed and metamorphosed keratophyres of a type that finds no analogy among the rocks of the Middle Devonian Series. All the rocks of this hill seemed to have been recrystallised under the metamorphosing influence of the adjacent granite. The details of the petrography are given below.

About a quarter of a mile south of this, is a large mass of tuff-breccia, lying east of the serpentine, but very closely resembling some of that to the west in the Middle Devonian Series.

The purely sedimentary rocks, in addition to the banded cherts, are jaspers, phyllites, rarely so fissile as slates, and generally pale brown or green in colour. These pass into jaspers, or are veined or interstratified with jasper. There is no exact analogy for these rocks among those of the higher series, unless they are derived from the Upper Devonian mudstones, which seems unlikely. It is these rocks, if any, that are to be considered of Lower Devonian age. It is quite impossible to estimate their thickness.

2. *The Tamworth Series of Middle Devonian age.*

The main interest in the stratigraphical portion of this paper, lies in this division of the geological record. We cannot yet, however, be certain as to the relative thicknesses of the subdivisions that have been adopted. The zones proposed depend partly on their lithological character, partly on the fauna of their associated limestones. In place of the single horizon of limestone formerly recognised, three are now believed to be developed, though the position of one of them is scarcely known at present. The three, in probable chronological order, are as follows: the Nemingha Limestone, the Loomberah Limestone, and the Moore Creek Limestone.



Text-fig. 1.—Columnar Section of the Devonian Series in the Tamworth District.

To see the succession most clearly, we must commence at the anticline in the valley of the Seven Mile Creek, and follow west along the line of section described by Messrs. David and Pittman. The lowest beds are radiolarian claystones, in places more or less cherty, and associated with several bands of tuff. Above them comes a narrow band of limestone, bent sharply by the anticline. It is not more than fifty or a hundred feet thick, and is so altered by the contact-effect of the adjacent granite, that its fossil-content is scarcely recognisable. The presence of *Favosites*, *Alveolites*, *Diphyphyllum*, and a pentameroid shell, was noted by the previous observers. For reasons which will appear subsequently, this limestone is considered to be on the same horizon as that which we have termed the Nemingha limestone. It is associated with more or less tuffaceous material. Above this commence the great thicknesses of radiolarian cherty claystones with lenticular, interbedded, radiolarian limestones, and vast quantities of pyroclastic material, that form the bulk of the Middle Devonian Series. Not far above the limestone, however, is frequently found a finegrained, grey, quartzitic rock, and, above this, is the greatest and most persistent of the zones of igneous rock. In this portion of the district, the Igneous Zone is composed chiefly of pyroclastic rock, though, elsewhere on this horizon, large masses of spilite and spilite-porphyry are developed. For convenience of reference, all the Tamworth Series up to and including the Igneous Zone are here classed as the Lower Middle Devonian Series.

The Upper Middle Devonian Series, above the Igneous Zone, consists of a great thickness of cherty radiolarian claystone, and banded cherts, with lenticular masses of radiolarian limestone, interstratified with pyroclastic rocks. This extends uninterruptedly up to the base of the Baldwin Agglomerates in the Upper Devonian Series. If we anticipate the discussion of the distribution of this series, however, it will be seen that, on two horizons in this sequence, limestone might occur. Northwards of Messrs. David and Pittman's line of section, the large mass of limestone on Moore Creek will be found to lie among radiolarian cherts above the Igneous Zone, but far below the Baldwin

Agglomerates. The horizon so determined is taken as the Moore Creek limestone horizon. South of the limits of the present map, in the Parish of Loomberah, is a richly fossiliferous limestone also occurring a short distance above the Igneous Zone, but differing in character from the Moore Creek limestone. This is accepted as marking another horizon, that of the Loomberah limestone. Very little is known of it as yet, and its relation to the Moore Creek limestone is undetermined. The presence of this limestone in the area covered by the present map is not fully proved, though two unfossiliferous masses in the south-eastern corner probably belong to it.

Fossils of the Tamworth Series.—The fauna of the Nemingha and Moore Creek limestones is tabulated below:—

Nemingha Limestone.	Moore Creek Limestone.
Lower Middle Devonian.	Upper Middle Devonian.
	*Lithistid Sponges (several undetermined species).
Favosites gothlandica var. *moonbiensis.*	*Favosites gothlandica.*
	F. basaltica var. *salebrosa.*
F. multitabulata.	*F. squamulifera.*
F. pittmani.	**F.* sp., cf. *pittmani.*
F. sp., cf. *forbesi.*	
**F.* sp.nov. α.	*F. crummeri.*
**F.* sp.nov. β.	**F. reticulata.*
	**F.* sp.nov. γ.
	**F.* sp.nov. δ.
**Stromatopora* sp.	*Stromatopora* sp.
**Stromatoporella*(?) sp.	*Stromatoporella*(?) sp.
**Diphyphyllum porteri.*	*Diphyphyllum porteri.*
	**D. giganteum.*
	D. robustum.
	**D.* sp.nov.
	Spongophyllum giganteum.

**Tryplasma*, sp.†	
**Sanidophyllum davidis.*	*Sanidophyllum davidis.*
**Alveolites* sp.	*Alveolites subæqualis.*
	Litophyllum konincki.
	**L.* sp.nov.
	Actinocystis cornu-bovis.
**Cyathophyllum*, sp.nov.	*Cyathophyllum obtortum.*
	Microplasma parallelum.
**Heliolites porosa*	*Heliolites porosa.*
**H.* sp., cf. *interstincta.*	
**Syringopora* sp.	*Syringopora auloporoides.*
	S. porteri.
*Monticuliporoid.	
Crinoid-stem ossicles.	Crinoid-stem ossicles.
Pentameroid brachiopod.	**Pentamerus* sp., cf. *knightii*
**Athyris* sp.	
**Zygospira* sp.	
**Cœlospira*(?) sp.	
	**Atrypa* sp.
	**Aviculopecten*(?) sp.
**Cyclonema* sp.	
Indeterminate gasteropod, four inches long.	**Vetotuba* sp.

In drawing up this table, the writer has had the privilege of using the collections of Mr. T. England, B.A., of Tamworth, and Mr. S. M. Tout, to whom he is greatly indebted, and, in these as well as in his own, occur several forms, kindly determined by Mr. W. S. Dun, which do not appear in the earlier lists. These have been marked with an asterisk.

It may be advisable to call attention to the points of difference in the two faunas. The Nemingha limestone is characterised by the abundance of *Favosites multitabulata* and of *F. pittmani.*

† Mr. Etheridge states that this species is very like *T. lonsdalia* var. *scalariformis*, which he has already recorded from the Nemingha Limestone (Memoirs Geol. Survey of N.S.W. Palæontological Series, No.13, p.81). He is preparing a description of this form, with others collected from the Devonian rocks of the Great Serpentine-Belt.

Stromatopora is fairly common, and a form of *Heliolites*, that is apparently not *porosa*, is occasionally present, while a certain species of *Tryplasma* is rather common The other forms are of less stratigraphical importance, and *Sanidophyllum*, though occasionally present, is very rare. The Moore Creek limestone is characterised by the abundance of *Sanidophyllum davidis*, *Spongophyllum giganteum*, *Actinocystis cornu-bovis*, *Syringopora auloporoides*, *Litophyllum konincki*, and *Heliolites porosa*, the last often forming very large masses. All these forms are rare or not developed in the lower limestone.

The study, by Dr. Hinde, of the radiolaria of the Middle Devonian Series included the description of fifty-three new forms(**10**); others still await description.

The Upper Middle Devonian claystones, but not, so far as is at present known, the Lower Middle Devonian, contain numerous casts of *Lepidodendron australe*, both in its normal form, and in the *Knorria*-condition. It may be found especially in Long Gully, and also in Loder's Gully, but is not so abundant here as it is in the Upper Devonian rocks.

Distribution of the Lower Middle Devonian Rocks.—Taking the limestone (associated with tuff), the cherty and quartzitic rocks, and the Igneous Zone as the characteristic rock-types of the Lower Middle Devonian Series, let us trace them northwards and southwards from the above-mentioned line of section, to ascertain the structure of our area. The northward-pointing arch of the limestone in the anticline in Seven Mile Creek, is met by another pointing southwards, and very sharply bent. Its two branches are close together, and, traced northwards, appear at intervals all the way to Moore Creek. They form narrow, lenticular patches generally closely associated with pyroclastic rocks, and frequently completely surrounded by them, or appearing merely as large or small inclusions of limestone in a mass of pyroclastic rock. This passage of a band of limestone into an igneous breccia containing fragments of limestone is a constant feature of this horizon throughout the whole of the Serpentine-Belt, as was pointed out in earlier papers, and is particularly well exhibited in the Nundle District(**15**). It is also

seen in the Middle Devonian Series of the Dillenburg district, in Germany(**18**), in the Carboniferous formation of the Isle of Man(**19**, Vol. ii., p.25), and elsewhere. As will appear later (p.574), the same structure is developed in the Ordovician Series of the West of Ireland, in association with a varied group of rocks, some of which are remarkably like those of the Middle Devonian formation of New South Wales(**20**).

The various outcrops of limestone do not join up regularly into two lines continuing the branches of the Seven Mile Creek anticline. Sometimes three lines are present, sometimes only one. The grey quartzite appears here and there in small amount. The occurrences of pyroclastic rocks, which are indicated on the map in a generalised manner only, are equally irregular in their development, though all are approximately parallel. The dip of the rocks is very steep (60°-85° to the N.E. or E.N.E.), and the exposures in the steep easterly-flowing gullies show much shearing and shattering. All these features indicate that the Lower Middle Devonian Series in the narrow zone along the margin of the granite-massif, is affected by much strike-faulting and repetition, as well as simple folding. Intrusive into those rocks are some small basic sills of porphyrite; that occurring in the south-western side of portion 158, Woolomol, has phenocrysts of basic labradorite, and has suffered very little from the metamorphosing effect of the granite when compared with the pyroclastic rocks.

We return to Seven Mile Creek, and now trace the Lower Middle Devonian Series to the south-east. The continuous band of limestone ceases by the Loder's Gully track to Tamworth, but is represented beyond this by small isolated lenticular masses which run round the wide open valley of Seven Mile Creek, and, swinging round in a rough semicircle, are found again in the small ridge west of Tintinhull railway-platform.

Here the limestone is again associated with a small amount of pyroclastic matter. Below the limestone, the regular sequence of outcrops of claystones and tuffs curves in a similar manner, dipping to the south-west, south, and finally to the south-east. To the east of the anticlinal axis, they follow parallel to the boundary of the granite, and dip steeply to the north-east and

north. They have here undergone considerable metamorphism, which has increased their resistance to erosion, so that they form a ridge between the granite and the valley of Seven Mile Creek. Thus this arching of the strata is not a simple anticline, but an ovoid pericline. The discontinuity of some of the beds suggests that some faulting is also present, but this cannot be proved. An apparent thickness of about a thousand feet of strata is exposed below the limestone.

Above the limestone are, here and there, masses of the fine-grained quartzitic rock, and a thickness (at Tintinhull) of approximately four hundred feet of claystones with some radiolarian limestones, and a small amount of pyroclastic material. Elsewhere this zone is of greater thickness. The angle of dip at times is quite small; one has been measured as low as 5° to the S.S.W. Above these comes the great mass of pyroclastic rock, which makes up the Igneous Zone. It is not more than one hundred feet thick at the head of Loder's Gully, but increases in width to the south, the outcrop being more than a quarter of a mile across. The very indented outline of this mass is partly the result of an interdigitation of claystones and tuffs, but may also indicate some repetition of beds by strike-faulting. The wide zone of pyroclastic rock forms the crest of the ridge between Loder's Gully and Seven Mile Creek, and, swinging round in conformity with the limestone, and becoming more coarse in grainsize as it turns, it is partly replaced by massive igneous rock (porphyritic spilite) about half a mile south-west of Tintinhull railway-platform. The line of junction of the massive and pyroclastic rock is not anywhere visible; indeed, there seems to be a passage between the two. On either side of the massive rocks is a varying amount of pyroclastic material, usually fine-grained. It varies somewhat in character; sometimes it has a granular base with a grainsize of about 0·5mm., but more usually the base is aphanitic and more or less vesicular. Except for the presence of vesicles, the rocks are very similar to those which occur in the Eastern Series, in the Nundle district(**17**, p.146). With these is a finegrained, apparently massive rock, which microscopical study shows to be pyroclastic. The matrix of the

rock is the same as that of the more finely granular spilite-porphyrites, and contains some well shaped phenocrysts, but the majority of the larger grains, which are only 0·2 mm. in diameter, are fragments of albite-crystals. There are also fragments of a pilotaxitic, felspathic rock rather poor in ferromagnesian minerals (keratophyre), as well as others richer in these minerals (spilite). This rock is one of the most finely granular of the rocks which seem to have a character intermediate between that of massive and pyroclastic types.

The petrological character of this complex must be our guide to further unravelling the stratigraphy of the Lower Middle Devonian Series. The wide alluviated valley of the Cockburn River obscures any direct linking of the formations across the stream, but the exact equivalent of the Tintinhull spilite is found to form the small hill in portion 48, Parish of Nemingha, by Pullman's farm. The hill, which is probably divided by a fault, consists of two masses of porphyritic spilite, separated by a band of pyroclastic material. The upper mass shows some indefinite signs of ellipsoidal partings. The dip of the associated beds (W. 10° N. at 40°) shows that a syncline exists below the river, and that this spilite-mass may well be the same band as that occurring at Tintinhull. As this rock was fairly free from epidote, it was chosen for analysis, and proves to be thoroughly albitic (see No.1130, p.602).

Eastward of this hill, are phyllitic claystones and quartzitic rocks, resembling those that lie between the Igneous Zone and the limestone. But, in place of the limestone, the igneous band appears again, southwards from portions 66/148; its reappearance is probably due to a fault, rather than to anticlinal folding, as the dip is to the west also. The igneous series here consists chiefly of pyroclastic material, but on its eastern side is a mass of porphyritic spilite like that at Tintinhull. The thick pyroclastic series extends southwards for over two miles, and forms the greater part of the hill, which we will term West Gap Hill (see Topographical Map, Pl. xlix.). The indented outline of the igneous rock, and its repetition, probably indicate the presence of a group of strike-faults here. The nature of the rock varies

to a certain extent; parts of it are richer than the remainder in fragments of keratophyre, and very coarse-grained agglomeratic rock, part of which is very ferruginous, occurs immediately west of the Gap. Associated with these is a red finely granular to aphanitic tuff, that appears quite massive in hand-specimens, save for the presence of a few larger fragments. The associated cherts are interbedded with tuffaceous material, and the beautiful instance of an intrusive tuff, which is discussed below, came from this spot. See Text-fig.5 and Plate liii., fig.10.

The mass of tuffs and breccias is invaded by a small intrusion of dolerite in the southern end of the hill. On the northern end of the hill, a spur runs towards the forking of the roads. This consists very largely of banded claystones and grey quartzite like that at Tintinhull. At the base of the hill, and following up the Gap Road, is a series of limestone-outcrops. One of these, the large mass exposed in portion 163, was the source of the fossils described by Mr. Etheridge from "Beedle's Freehold"(**11**). The limestones north of the Gap are usually grey or white, and are more or less associated with tuffaceous material (see p.575). South of the Gap, the limestone has a reddish colour, doubtless connected with the presence of ferriferous keratophyres. (See chemical analyses, p.611). A small quarry was opened in these to exploit the Nemingha crinoidal marble: several varieties of ornamental stone were obtained, of which beautiful examples may be seen in the museums of Sydney, particularly the Technological Museum. [See the coloured illustration in(**13**)]. The stone has not yet been put to much use commercially. This is the typical occurrence of the Nemingha horizon, and the stratigraphical details mentioned above are the grounds upon which it is correlated with the limestone of Seven Mile Creek. For some distance south of here, as will appear more particularly in a later communication, the limestone is directly associated with massive, brecciated, ferruginous rocks, keratophyres and the like, and is separated from the Igneous Zone by a considerable thickness of claystones and cherts. The close approximation of the limestone and the Igneous Zone in the Gap must be due to faulting. A small fault is visible by the limestone-quarry, marked by

a breccia of red and white limestone. The fauna of this limestone has been tabulated above.

Directly east of the Nemingha limestone zone is the largest mass of porphyritic spilite that occurs in the district; it forms the ridge termed East Gap Hill. This, also, must be correlated with the Tintinhull spilite. The southern end of the hill consists of pyroclastic rocks, with the seemingly massive, ferruginous keratophyre-breccia like that on West Gap Hill. This passes without any junction-line into a very vesicular porphyrite, and, on the top of the ridge, into a slightly vesicular porphyrite, with phenocrysts of albite, and a subvariolitic groundmass of felspar, uralite, and chlorite (see Text-fig.4, p.565). Except for the greater abundance of the felspar, the mineral-composition is exactly that of the spilites of Tintinhull, and there is little reason to doubt that this is but a thicker, and more coarsely crystalline portion of the same mass as the other rocks, brought by faulting or folding into its present position. The northern end of East Gap Hill is occupied by a mass of rather decomposed dolerite, which invades the spilite-porphyrite, and extends nearly to the Cockburn River. This intrusion is partly albitic, but the greater portion contains andesine, or labradorite. We will return subsequently to discuss the manner of origin of the igneous rocks of East Gap Hill (p.564).

Eastwards of this occurrence of the Igneous Zone, we can not determine the tectonic structure with any degree of probability. No further zones of igneous rock occur, which resemble either the spilite-porphyrite, or the ferruginous keratophyre-breccias described above. Moreover, the angles of dip of the strata, when observable (and this is but seldom), afford no help, being usually almost vertical. However, the large mass of limestone in portion 91 and the eastern end of 88, though too altered for the preservation of fossils, resembles that of the horizon last described, and may be supposed to be the limestone that should occur below the spilite-porphyrite of the Igneous Zone on East Gap Hill. Isolated lenticles of limestone occur on the same horizon in portion 168, and are included in a mass of tuff-breccia in portion 207, while a possible continuation of this zone is shown

by the small patch of limestone in the keratophyres of portion 175 (see p.572). The lenticles of limestone that lie about a quarter of a mile east of this line, in portions 180 and 216, are probably on the horizon of the Loomberah limestone. They are white, crystalline rocks, free from pyroclastic impurities, and all trace of fossils has been lost. East again of these, there is another line of doleritic intrusions, lying along the western side of Spring Creek. These may perhaps be correlated with the Igneous Zone. If so, we may class with the Nemingha horizon the series of limestones that occur in the creek-valley, and commence to the north with the large mass of metamorphosed limestone, in portions 88, 91, and 118, which is exactly like that described above. This is followed to the south by a series of small lenses of limestone, generally intimately associated with pyroclastic rocks, occurring in portions 126, 216, and 153. At the southern edge of the map in portion 121, is a large lenticular mass of white crystalline limestone, quite free from traces of fossils, about 400 yards long and 60 yards wide. This is probably on the same horizon as the limestone that occurred on the boundary of portions 180 and 216, and may tentatively be classed with the Loomberah limestone. The stratigraphy of the southern end of the area mapped is quite indefinite. To complete the tracing of the structure-lines, as far as is possible, one may note that, east of Spring Creek, in portions 113, 119, and 123, is a mass of highly altered dolerite, and other basic rocks, which may represent still another repetition of the Igneous Zone. Further repetitions of the rocks of the Lower Middle Devonian Series occur, as has been noted above, among the rocks of the Woolomin Series, and, together with them, make up the Eastern Series, which lies east of the Serpentine-Belt.

Distribution of the Upper Middle Devonian Rocks.—This series has been defined as that extending from the Igneous Zone, which closes the Lower Middle Devonian, upwards to the Baldwin Agglomerates. It includes the Loomberah and Moore Creek limestones, but, as these occur at opposite ends of the area mapped, their relation to one another is not known. Apart

from these limestones, the Upper Middle Devonian Series is a monotonous succession of radiolarian claystones and cherts, with lenticular intercalations of radiolarian limestone, frequent casts of *Lepidodendron australe*, preserved in the radiolarian rock, with abundant masses of interstratified and intrusive pyroclastic rock, which show spheroidal weathering particularly well in the railway-cuttings. The interstratified tuffs may also show casts of *Lepidodendron* or contain radiolaria.

The limestones which occur at the extreme south-eastern end of the map, which, also, have been correlated with the Loomberah limestone, and the cherts associated with them, probably belong to this series; but the southernmost definite instance of its occurrence is afforded by the rocks that form the western slopes of West Gap Hill. The zone occupied by the series then follows the flexions of the Lower Middle Devonian rocks, bending with syncline and anticline, passes up Loder's Gully, and forms the hills by the Tamworth trigonometrical station, and the western slopes of the ridge extending to Moore Creek. Here the limestone occurs in abundance, and is the type-occurrence of the Moore Creek limestone. Only one band is present, but, as shown on the map and sections, (Plates l.-li.) it is much folded, faulted, and repeated. The previous writers have stated that the limestone reaches a thickness of 1000 feet, but the writer has not seen any section showing a thickness of limestone which one can with safety assume to be more than 450 feet. The evidence available is too poor to admit of a more definite statement than this. The masses of limestone are lenticular in shape, and thin out, and disappear about a mile south of the creek. They are directly underlain and overlain by radiolarian cherts.

The greater part of the Upper Middle Devonian Series is repeated by the fault that runs along Spring Creek through the Tamworth Common, which fault was discovered by Messrs. David and Pittman(**9**). This is not a simple fault, however, but a fault-zone or plexus. In several places, the faults are made very obvious by the fact that the adjacent rocks have been strongly silicified or even metasomatically replaced by quartz, owing to the action of siliceous solutions rising in the fault-fissures. The

lowest beds made visible by the fault are the clayshales and cherts, immediately underlying the limestone, which is obviously of the same character as the Moore Creek limestone, is silicified in the same way, contains precisely similar fossils, and is associated with similar rocks. The silicification of the limestone is very irregularly distributed ; portions of some fossils may be replaced by silica, a sort of beekite, while the remainder may be pure calcite. Again, long or short, irregular, siliceous bands occur quite apart from the fossils, or, again, the fossils may be found to have merely an outer skin of silicification. The limestones on Spring Creek are divided up into small masses, partly, no doubt, by the plexus of faults (sometimes marked by fault-breccias), but also owing to the fact that they were originally formed as small lenticles, or masses which interdigitated with the claystones. This is clearly seen in a small cutting below the Corporation's stone-crushing mill (see Text-fig.2). These claystones

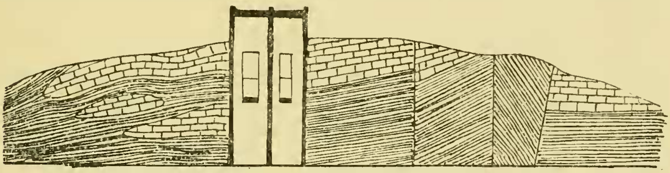


Fig.2.—Lenticular coral-limestone and radiolarian claystone of the Moore Creek horizon, exposed in road-cutting by the rock crushing plant on Spring Creek, Tamworth Common.

are of the normal siliceous type; they are not calcareous mudstones, such as one might expect if the coral-reef, that is now limestone, had risen to the surface of the sea, and had come under the shattering influence of the waves. In this way, the Tamworth and Moore Creek limestones differ from the Devonian limestones of Ohio, that were described by Grabau, and from other limestones of a like character(21).

Neither the Moore Creek nor the Tamworth limestone-occurrences are closely associated with any igneous rock, though a short distance above the limestone at Tamworth are a few thin bands of pyroclastic rock, and some very narrow layers of felspathic tuff, which show the clearest evidence of their intrusive

character. Little veins, that break across the stratification of the claystones, project outwards from the otherwise apparently interbedded tuff. It was first pointed out to the writer by Mr. Aurousseau, B.Sc., that one of the bands of igneous rock about a yard in width, though no different to the naked eye from the normal fine-grained tuff, was really a massive and thoroughly albitised spilitic dolerite. Though a number of other fine-grained igneous rocks in the Upper Middle Devonian series have since been subjected to microscopic examination, this is the only massive rock yet found in that series. It occurs in the road-metal-quarry, at the southern end of the ridge beside the creek. In this quarry, and in that adjacent to it, are the most accessible examples of the interbedded lenticular radiolarian limestones. They occur up to six feet in length, and nearly two feet in width, but the majority are smaller than this. Some sign may at times be seen of a structure that has been most clearly observed in a limestone-lens at Nundle, namely, that the same lines of stratification as are in the adjacent mudstone continue right through the limestone, but are much further apart here than in the claystones. The bedding-planes of the claystones, therefore, appear to bend inwards at either end of the limestone-lens, and thus to follow its outline (see Text-fig.3). Presumably the lens was

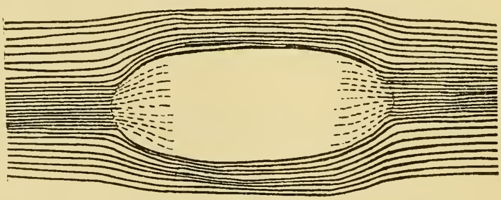


Fig.3.—Lenticle of Radiolarian Limestone.

formed by segregation of lime in the soft unconsolidated muds, which have subsequently been much more closely compacted by pressure of overlying sediment, etc., than the solid lens which had formed in them.

Below the limestone at the southern end of its outcrop, is a small anticline noted by the previous authors. It seems, how-

ever, to be most probably only the dragged-down edge of the strata adjacent to the fault.

West of this limestone-horizon, is the monotonous series of claystones and lenticular radiolarian limestones extending to the foot of the ridge between the Moore Creek and Manilla roads, which ridge is composed of the Baldwin agglomerates. For this reason, the claystones must be correlated with the cherty rocks that lie below the agglomerates, at the mouth of Long Gully, and would, therefore, indicate that a variation of the degree of silicification may occur when a series is traced along the direction of the strike. Such variation is, indeed, very common in the rocks of the Upper Middle Devonian Series, and often causes uncertainty as to the proper correlation of isolated occurrences.

The repetition of the Upper Middle Devonian Series is found again on Moore Creek, where the limestone itself is repeated in the small hill in portions 41, 42, 43 of the Parish of Woolomol, which is the top of an anticline. This limestone is exactly similar in all its features to the other large mass of limestone on the southern side of Moore Creek, and must clearly be correlated with it. Unfortunately, the whole of the central part of the Parish of Woolomol is covered with drift, so that the details of the stratigraphy are hidden. It may be safely assumed, however, that a fault separates the limestones in portions 41-43 from the pyroclastic rocks immediately to the west of them, as the intervening distance is far too small to permit of the unhindered development of that part of the Upper Middle Devonian Series which lies between the horizon of the Moore Creek limestone and that of the Baldwin Agglomerates.

The geological sequence is very indefinite south of the Peel River owing to the want of clear exposures. The Baldwin Agglomerates may be recognised on the hill east of Goonoo Goonoo Creek, and all the country east of these is made up of slightly silicified and soft radiolarian claystone, with lenticular limestones and pyroclastic intercalations. These most probably belong to the Upper Middle Devonian Series, but it has not been possible yet to link up definite bands of pyroclastic rock with similar bands north of the river. The alluvium of the Peel

River seems to hide some line of faulting or discontinuity, in the lithological character of the country.

Igneous Rocks of the Middle Devonian Series.

In the foregoing, the more important occurrences of igneous rock have been briefly mentioned, but no attempt has been made to discuss the conditions attending their development. This we will now endeavour to do. The most varied and instructive area is that of East Gap Hill, of which a sketch map is given (Text-fig.4). Passing from north to south, one has :—

1. Massive dolerite.
2. Porphyritic spilite.
3. Spilite only slightly porphyritic.
4. Vesicular spilite.
5. Passage-rocks between vesicular spilite and breccia.
6. Breccia or agglomerate.

There exists a very clearly marked boundary between the first two, but a gradual passage between all the other members. There can be no doubt that the dolerite is intrusive into the cherts, and also into the spilites. The relations of the spilites are not so clear. Along the eastern, and presumably lower side of the igneous mass, the boundary of the spilite seems to transgress the bedding of the cherts, and is rather irregular, though it is not clear whether it should be considered transgressively intrusive into consolidated cherts, or merely into the semi-liquid unconsolidated sediments on the sea-floor. This point was discussed in another connection in the previous paper(17). The igneous rock along this eastern (lower) side is locally brecciated, and such breccias, often with the relations of intrusion-breccias, may contain very vesicular patches. These vesicular patches of breccia may grade into massive vesicular rock and thence into the dense solid rock of the main mass of spilite. This seems to indicate that the igneous mass was intruded into sediments that were at least partially consolidated. From this edge of the mass, there projects a narrow tongue of solid spilite a short distance to the east, but it is not clear that this is a feeding dyke; it may be merely a portion of the mass

displaced between two faults. The main mass of the intrusion, occurring on the top of the ridge, contains large and abundant phenocrysts of albite. These decrease in size as the rock is traced to the south, and the rock at the same time becomes more

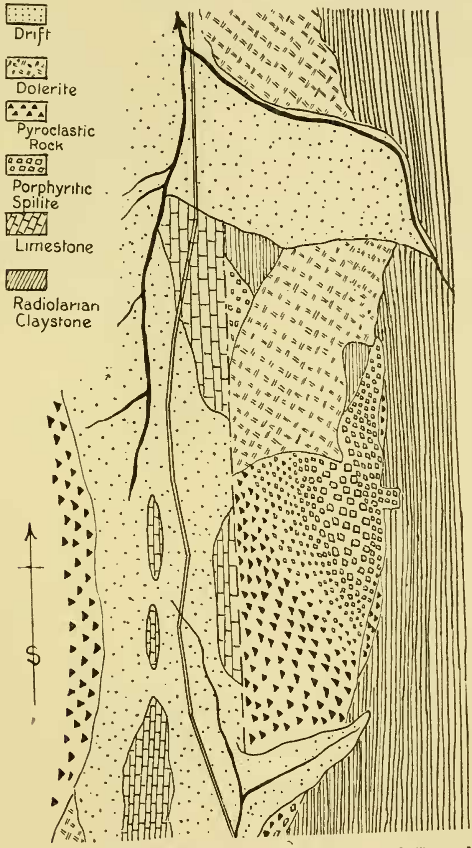


Fig. 4.—Sketch Map of the East Gap Hill Complex.

and more vesicular; it begins to take on a reddish tint: fragments make their appearance, and imperceptibly one passes into breccias and agglomerates, composed of more or less ferruginous keratophyres or spilites, in which the ferromagnesian minerals have been destroyed, leaving only a red staining of hæmatite. These

are described in detail in a later portion of this paper. The relation of these breccias to the overlying sediments is obscured by drift. The Nemingha limestones follow immediately west of the hill, but are believed to be separated from the igneous rocks of East Gap Hill by faulting. They show no sign of contact-alteration, and there is other evidence of the presence of one or more strike-faults running through the Gap itself, *e.g.*, in the presence of a fault and a band of fault-breccia traversing the limestone in the "red marble" quarry in Portion 134. The problem is rendered more complex by the presence of tuffs in intimate association with the limestone, which often cannot be distinguished from those that occur in the Igneous Zone and lie stratigraphically several hundred feet above the limestone.

The igneous rocks of West Gap Hill are almost entirely fragmental. They are quite similar to those of East Gap Hill, of which they are, it is believed, the faulted equivalent They are sometimes very coarsely granular, the fragments being several inches in length, and include cherts and limestones, as well as igneous rocks. The cherts form particularly large angular pieces. This mass of fragmental rock is invaded by massive albite-dolerite, which occurs on the southern end of the hill. Various exposures show the relation of the pyroclastic and sedimentary rocks to one another, and the frequently intrusive nature of the former can be thoroughly substantiated. No single specimen, however, is more instructive than that shown in Text-fig.5, and Plate liii., fig.10. This consists of green banded chert, with intercalated bands of purplish pyroclastic material, which have a sharply marked boundary on the one side against the chert, and a gradual passage between the two rocks on the other. This is clearly due to successive small eruptions of tuff, which filled the sea with fine ash, that deposited in layers at first sharply distinct from the clay on to which it fell, but faded away gradually upwards, as the slowly settling remnants of the ashy material became more and more mixed with the normal sediment (radiolarian clay). Intrusive into this banded rock, and cutting across its bedding-plane, is a tongue of breccia, of the same composition as the interbedded tuff, though of larger grain-size.

The writer has not been able to find an account of associations of pyroclastic rock and sediment exactly similar to those of the

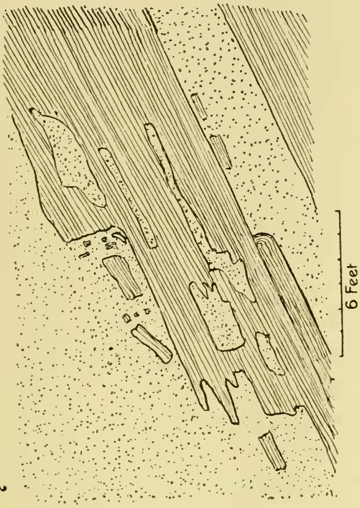


Fig 6.

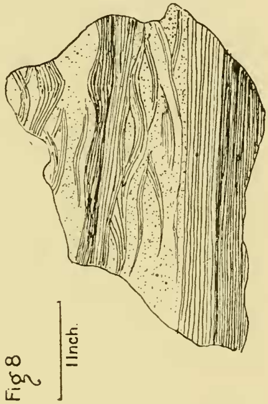


Fig 8

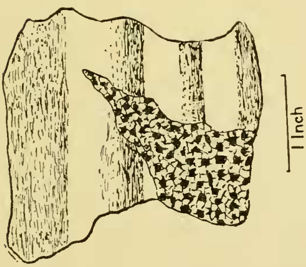


Fig 5.

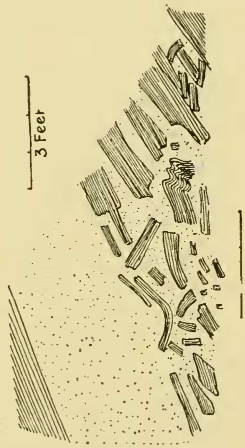


Fig 7.

Fig. 5.—Interbedded and intrusive pyroclastic rock, West Gap Hill.
Figs 6-7.—Intrusive pyroclastic rocks, Railway-cutting, Nemingha.
Fig. 8.—"Eddy-bedding" in claystone and tuff, Railway-cutting, Nemingha.

Tamworth District,* and has been led to adopt tentatively a rather speculative explanation of the features present. A fact

* See Postscript to this paper.

that is difficult to understand, is the almost complete absence of glassy matter among the pyroclastic rocks. As will be seen, they consist *(a)* of fragments of rocks passed through by the ascending igneous material, chert, limestone, etc.. and *(b)* fragments, isolated crystals, and portions of crystals from medium- and fine-grained rocks of the dolerite-spilite-keratophyre series. In the case of the "intrusive tuffs," the rock consists largely of grains of minutely crystalline trachytic keratophyre, which recall the constituent granules in the brecciated keratophyre of Hyde's Creek(**17**). Though the ascending magma must have been rapidly chilled by the wet sediments, it must also have been charged with a considerable amount of water, from which it could not free itself. There would thus be a mineraliser constantly present during the period of consolidation, which might partly account for the advanced crystallisation, frequently very minute, of the rock.. Also, any glass that formed in these conditions would probably be rapidly devitrified, and, indeed, much of the crypto-crystalline grains may be devitrified glass. The movement of the molten material below would break up the crust as it consolidated, and it would also be shattered by the strains produced in the necessarily rapid variations in temperature, so that, above the level where the crystallisation took place, the comminuted igneous material would move forward in the form of a watery slurry or mud. This mud would escape from the vent in which it rose, by the path of least resistance, which, under a considerable overburden of silt and sea-water, might sometimes be by intrusive injection into the surrounding partially consolidated sediments, at other times, by breaking through and discharging into the sea. This would doubtless be accompanied by more or less energetic convulsions. In the latter case, the igneous material would settle down on the sea-floor, as a band of tuff, either pure or mixed with normal marine sediment. Hence might arise the well ascertained fact, that it is often quite impossible, by purely petrographic means, to distinguish between a sedimentary and an intrusive pyroclastic rock in this district.

An objection to this explanation, which cannot yet be satisfactorily answered, is the uncertainty that the greatest depth

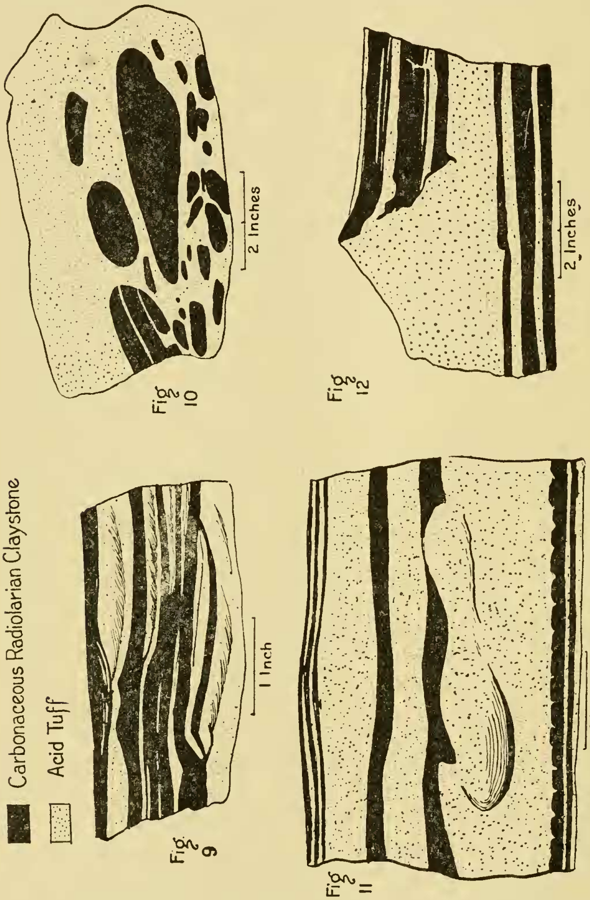
which we can assume for the sea in which the sediments were deposited, would give an overburden of water and silt sufficient to act in the manner indicated. There would also need to be a rather nice adjustment of the rate of protrusion of the magma. If it were greater than that necessary for the development of intrusive tuffs, masses of lava would invade the sediments, and different features would result.

It seems possible to explain thus the passage between the massive and brecciated igneous rocks seen on East Gap Hill, and also, though not so clearly, on the ridge north-west of Tintinhull Railway-platform. The upper portion of a mass of lava intrusive into, or flowing through wet, semi-consolidated sediment, would naturally be especially liable to brecciation. Again, the abundant opportunity offered by such brecciation for the passage of solutions would be exceptionally favourable for the destruction of the ferromagnesian minerals, and the oxidation of their iron-content to magnetite and hæmatite. To some such processes, the peculiar features of the red breccias and agglomerates of East and West Gap Hills may owe their origin.

The sections exposed in the railway-cuttings between Tamworth and Tintinhull, particularly those immediately east of Nemingha, afford further examples of this phenomenon, as will be seen from the features illustrated in the figures herewith. (Text-figs.6,7,10,12).* An intrusion of pyroclastic material into partially consolidated sediment might be expected frequently to transgress the bedding-planes of the sediments, to crumple them, and to include numerous crumpled or uncrumpled fragments of them. The exposures illustrated clearly exhibit these features, and further indubitable evidence of intrusion is afforded by the microscopical preparation illustrated in Plate liii., fig.6. The original of this is in the collection of the Geological Survey of New South Wales (No.1190), and was one of the slides used by Messrs. Pittman and David in the preparation of their work. The writer is indebted to these gentlemen for permission to

* Compare with these illustrations the figure given by Sir A. Geikie of a breccia invading a slate (19, Vol. ii., p.50, fig.198). The explanation of this feature is not, however, applicable to the Tamworth rocks.

illustrate it here. Again, lateral injections and explosions within unconsolidated sediments of the character we are considering, would be accompanied by more or less sliding of the lamellæ over one another, which would result in the tearing up



Figs. 9 and 11.—Effect of lateral thrust on unconsolidated, interlaminated acid tuff and carbonaceous claystone, Railway-cutting, Nemingha.
Fig. 10.—Intrusive tuff with rounded inclusions of carbonaceous claystone.
Fig. 12.—Tuff intrusive into carbonaceous claystone, Railway-cutting, Nemingha.

of the lamellæ, and their injection into one another. This is particularly well shown when black carbonaceous layers alternate with white tuff. A specimen of this is illustrated by Text-figure 11. Again, the small convulsions caused by the ejection

of material, would occasion some oscillatory movement in the water on the sea-floor, which might result in a sedimentary structure resembling current-bedding in the mass of the silt lifted and redeposited at each convulsion. The specimens illustrated by Text-figs. 8 and 9 may perhaps be an example of this. We may compare with figure 8, the illustration of false bedding in chert seen by Clements in the Pre-Cambrian rocks of Michigan, which are also associated with tuffs (**22**, Plate xxvii.). It must be noted, however, that ripple-markings were seen among these rocks by the previous authors(**9**). According to Hunt(**23**), these do not necessarily indicate a very shallow sea. They may form at considerable depths, as much as 188 metres in one instance cited. It is not clear to the writer whether the features seen in Text-fig.8 are the result of a general rippling oscillation or eddying produced as suggested above. The extremely local character of the phenomena may indicate that the latter alternative is the more probable.

Intrusions of pyroclastic rock into more consolidated chert would require more energetic explosions than those described above, and would result in much shattering. Rocks which illustrate this are very frequent along the west side of the serpentine in Spring Gully, and have been found in the Nundle District(**17**, pp.166-7.* See also p.575).

The conception here advanced, of the semi-liquid nature of unconsolidated fine-grained sediments, is in accord with the results of Dr. Sorby's studies(**34**). Injection of pyroclastic material into sediments with varying degrees of consolidation down to that of a "creamy" (*op. cit.*, p.197) consistency, would naturally result in an appropriate variety of intrusion-phenomena. Ejection into the open water, and normal sedimentation would be the limiting case.

Another igneous complex of great interest occurs in Mr. MacIlveen's property (Portions 180, 175, and 162, Parish of Nemingha), about two miles south of East Gap Hill. A sketch-

* In the first part of this series of papers(14), a different explanation of the intrusive tuffs was suggested, but experience has shown it to be untenable, and it has been withdrawn(17, *loc. cit.*).

map of this is given in Text-fig.13. It recalls some of the features of the Hyde's Creek complex(**17**). The western side of the area sketched consists of normal, steeply dipping, banded chert,

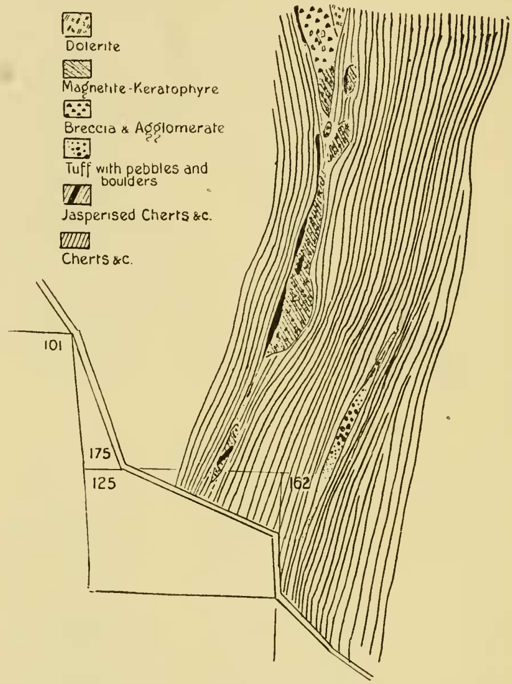


Fig. **13**.—Sketch Map, MacIlveen's Igneous Complex (Nemingha Parish).

which, at its contact with the keratophyre, is impregnated with hæmatite, or is changed into red jasper. The line of contact runs in a N.N.E. direction for half a mile, and then is deflected into a direction a little west of north. The keratophyre, east of this line, varies from a rock with very little iron-ore, to one rather rich in magnetite, which has been more or less replaced by hæmatite. There are also vesicular and slaggy varieties, as at Hyde's Creek. The keratophyre includes large fragments of limestone, and an intimate, breccia-like mixture of limestone, chert, and magnetite-keratophyre; it is also traversed by small

veins of red jasper, and hæmatitic chalcedony. In microscopic structure, the rocks have many of the features of the keratophyres in the breccias of the Gap Hills. When traced northwards, the keratophyre becomes mixed with breccia, and coarse agglomerates, containing large boulders of a magnetite-keratophyre-porphyrite, while the northern extremity of the complex is a mass of coarse agglomerate, 100 yards wide, mixed with intrusions(?) of vesicular hæmatitic keratophyre, and large intrusions of massive keratophyre-dolerite, beside which is a large mass of the porphyrite. Brecciated jasperised chert occurs on either side of this. It would seem that, in this area, the intrusion of keratophyric dolerite and porphyrite was followed by a disruptive invasion of keratophyre, which broke up or brecciated the massive rocks, and emitted siliceous and ferruginous solutions, which jasperised the surrounding cherts.

Less than 200 yards south of this complex, is yet another feature of the igneous activity of no less interest, though differing greatly from the above. A band of apparently normal tuffaceous rock, at least 500 yards long, runs through Portion 162, Nemingha. It contains numerous small pebbly inclusions at the northern end, which are either angular or rounded and smooth as if waterworn. As we follow the band southwards, the pebbles increase in size until the tuff is full of large boulders, often beautifully smooth and rounded, sometimes as much as a foot in diameter. These pebbles often fall easily out of their matrix, and one would scarcely doubt, from the inspection of a pebble so isolated, that its shape was due to water-erosion. South of the point where the pebbles reach their maximum size, they diminish rapidly, and in 50 yards they decrease to their original diameter of less than an inch, and the tuff-band continues thus across the road to the south without any interruption. The distance from the northern to the southern point where the pebbles are not more than half an inch in diameter, is scarcely 200 yards. On either side of this band, which reaches a thickness of 30 yards, is normal, undisturbed, fine-grained, banded chert. There is a clear affinity, in lithological character, between the tuff-matrix and the inclusions. With a few exceptions, the boulders, though

they may differ in macroscopic appearance, (they are purple, speckled grey, or green) prove to be porphyrites, composed of phenocrysts of augite and plagioclase, in a very fine-grained base. The exceptional rocks are certain rhyolitic keratophyres. The matrix is a brecciated crystal-tuff, of the same composition as the inclusions, and consists of minute fragments of these rocks, or of their phenocrysts. These are sometimes so closely and regularly packed together that it is difficult, at the first glance through the microscope, to distinguish between the matrix and the inclusion. These features must owe their origin to one or both of two causes: either the mass is a deposit of volcanic ejectamenta, which were rounded by attrition in the vent; or it is detritus from a volcanic cone, which reached above the surface of the water, and gave an opportunity for the shaping of the blocks by wave-erosion. It is difficult to decide which was the paramount factor. In either case, the rapid variation in the size of the boulders, shows that the rocks exposed were deposited near the source from which they were distributed, whether this be the centre of eruption, or the outlet of a valley which cut into the volcanic mass. The very small thickness of the mass, and the very regularly banded and minutely granular character of the sediments above and below the igneous material render the wave-erosion hypothesis difficult of application unless it be considered that this exposure is on the outer fringe of a large mass of ejectamenta, of which there is no other sign in the vicinity.

Another feature, which we may associate with the explosive action of the igneous eruptions, is to be found in the nature of the limestones. These show many features identical with those described by Messrs. Gardiner and Reynolds from the Ordovician rocks of the Tourmakeady District, County Mayo, Ireland. Besides the normal, massive, coral-bearing limestones, there are to be found, in the Parish of Nemingha, "limestones brecciated *in situ*, pink or white rocks, which, after being cracked into numberless pieces, have been recemented by the deposition of material into the cracks," and, even more frequently, "limestone-breccias, a coarse type of which contains angular blocks of lime-

stone, red, pink, or grey in colour, and horny or crystalline in texture, intermingled with angular blocks of red or green felsite," which, on microscopical examination, proves to be keratophyre or spilite, as the writer understands, is also the case with so-called felsite at Tourmakeady (see **20**). "The matrix, in which these blocks are embedded, is . . . . . . a calcareous ashy grit." The writer has "found no fossils in the matrix, although some of the included limestone blocks have yielded a rich harvest of fossils." The mass of limestone in Beedle's Freehold, Portion 163, Nemingha, is of this character. As in the case of the rocks described by Messrs. Gardiner and Reynolds, so here, "it seems impossible to avoid the conclusion that, after the deposition of the fossiliferous limestone, it was in some cases broken up by volcanic eruptions, and the fragments, accompanied by fragments of felsite, were embedded in a tuff which thus must be of later date than the limestones. It does not, however, follow that there was any very great interval of time between the deposition of the limestone, and its disruption, succeeded by the embedding of its fragments in a coarse tuff. . . . The view of the explosive origin of the limestone-breccia affords an adequate explanation of its patchy mode of occurrence." The writer cannot find words more appropriately descriptive of the brecciated limestone of the Nemingha horizon than those used by the authors cited.

One would naturally expect that brecciated cherts and claystones should occur in an analogous manner, either with or without intermingled tuff. Such rocks are well developed in the Middle Devonian Series west of the serpentines in Spring Creek, and are particularly abundant in the Eastern Series on the opposite side of the valley, which rocks are considered to be an infolded repetition of portion of the Middle Devonian Series. It is not necessary to describe these in detail; they are naturally connected by intermediate types with those described above (p.571).

There remain to be considered the more massive intrusive rocks. One of these is a porphyrite, the phenocrysts of which are greatly shattered, though the rock appears to be massive. This forms a small mass in Portions 213, 214, or 216, Parish of

Nemingha. It was, unfortunately, not exactly localised, and the writer could not find it on a second visit to the place of its discovery. It is described below (see p.598).

The intrusions of dolerite at the extreme south and north of the long complex, of which East Gap Hill is the central part, are normal dolerites, the felspar of which is labradorite; but several specimens from the central portion of this mass are albitic. So far as can be seen, there is no evidence of the formation of adinole in the cherts, associated either with the albitic or the non-albitic dolerites, nor is there any difference recognisable in hand-specimen between the two types of intrusive rock. The microscope shows that the albitic rocks are thoroughly uralitised, but some of the calcic dolerites are also considerably altered. The dolerite in Portion 166, Nemingha, contains veins of epidote, with which is associated a large amount of axinite. The discovery of this is due to Mr. D. A. Porter. Axinite also occurs in the vesicles of the spilite-porphyrite on East Gap Hill. Nothing more can be said as to the source of the axinite than was said concerning that of the Nundle district, namely, that it probably is derived from the basic rocks themselves, and is not necessarily a product of the intrusion of the not very distant granite (see **17**, p.126).

There are, finally, a few small intrusions of quartz-keratophyre, of which the largest occurs on the extreme south of the area studied, Portion 171, Nemingha, while a series of smaller intrusions are to be found along the eastern side of the East Gap Hill zone of igneous rocks, and an isolated occurrence a quarter of a mile north of Housefield's Hill in the Parish of Woolomol. The characteristic feature of these rocks is the very great amount of strain-effect which they exhibit: the rock breaks with a peculiar jagged fracture, the felspars are often bent and broken, and the grains of quartz are shattered and ragged, with very undulose extinction. The reason of this great exhibition of pressure-effects is not at all clear. One may recall the fact that the keratophyres of the Nundle district showed strongly brecciated structures, and the suggestion made previously (**17**, p.164), that possibly these rocks owed their character to movements acting

on a very viscous magma, during and after its consolidation. At the same time one must note as a fact at present without explanation, the very considerable resemblance between these acid quartz-keratophyres, and the veins of quartz and albite, that occur in the serpentine in other parts of the Serpentine-Belt (see **16**, p.691).

Barraba Series (of Upper Devonian age).

Two divisions of the Upper Devonian Series are recognised; the lower is the Baldwin Agglomerates, and the upper the Barraba Mudstones. This is in conformity with the classification adopted in the first part of this series(**14**). However, since the lower agglomerates are frequently not developed, it seems best to extend the term Barraba Series to comprise the whole of the Upper Devonian formation, and to recognise the Baldwin Agglomerates merely as a basal zone, which may or may not be present. Both divisions occur in the Tamworth District. We commence with the discussion of the agglomerates.

It was stated in a previous paper(**14**, pp.500-1) that the coarse agglomerates did not, as was previously supposed, rest unconformably on the banded claystones of what is now termed the Upper Middle Devonian Series, where they are exposed on the hills about Cleary's Selection, to the north-east of the Tamworth Common. The inference was drawn chiefly from a consideration of the lithological similarity between the matrix of the agglomerates, and the tuffs and breccias in the underlying Middle Devonian, as well as the overlying Upper Devonian rocks, and the criteria for the lithological proof of a conformity through continuous oscillatory change of condition, were discussed from a hypothetical point of view. This conclusion can now be thoroughly substantiated on stratigraphical grounds. The coarse agglomerates may be traced round the face of the hills from the Two-Mile Bridge, on the Peel River, south-east of Tamworth, until they meet the fault in Spring Creek, on the northern boundary of the Common. The boundary of the agglomerates is at every point, in complete conformity with the strike of the Middle Devonian rocks, on which they rest. Particularly clear proof of this, is afforded by the sections exposed

in Long Gully, Cleary's Gully, the small gorge in portion 246, and again in Spring Creek in portions 148 and 237, and is sufficiently indicated in the map herewith (Plate l.). The agglomerates are interstratified with mudstones, and these also show dips conformable with those of the underlying rocks. The small gorge cited above shows a very instructive exposure of these rocks. Again, as mentioned by the previous authors, there are frequently short irregular beds of pebbles in the agglomerates(**9**, p.23), and if these represent the bedding-plane of the agglomerates, as observations at Borah Creek Gap, in the Baldwin Mountains, near Manilla, convinced the present writer that they do, there is additional proof of the conformity here claimed.

The mode of origin of the agglomerates is not directly obvious. They consist of fragments of chert, andesite, porphyrite, keratophyre, and rhyolite, with some limestone, set in a matrix exactly similar to that of the normal pyroclastic rocks, which is made up of close packed fragments of crystals and rocks, evidently derived from rocks of the same nature as those which occur as included pebbles. These pebbles are frequently very smooth and rounded, particularly in the lower portion of the series, though some angular blocks occur. Professor David was of the opinion that they were waterworn in many cases, but was doubtful whether magmatic corrosion had not played some part in the rounding of some of the larger blocks(**9**). The boulders and fragments reach a diameter of nearly a foot in the neighbourhood of Cleary's Hill, but diminish in size as they are traced to the north-west or south-east, and are rarely more than half-an-inch in diameter, where the rock appears on the railway-cutting by the Two-Mile Bridge, or in the valley of Spring Creek. The source of these boulders was, therefore, in the neighbourhood of Cleary's Hill.

In many features these agglomerates are analogous to those previously described (p. 574), but differ from them in their immense thickness, which reaches a maximum in the Tamworth Common of nearly 2000 feet, but dies out by interdigitation with Barraba mudstones. These interstratified mudstones are richer in *Lepidodendron* than any other rocks in the district, and casts of this plant

sometimes occur in the igneous materail itself. There is thus less reason in this case to doubt the possibility of a volcanic cone rising above the surface of the sea. It must be noted, however, that there is not any great thickness of agglomerate, uninterrupted by intercalations of radiolarian mudstone, so that the sea-floor must have been sinking rapidly, and the islands, if formed, would not be of long duration. The largest rounded boulders are in the base of the series, lying on undisturbed claystones. The intercalated mudstones were not deposited on steep slopes, but are quite conformable with the claystones below the agglomerates, so far as can be determined; and the upper members of the agglomerate series show little or no sign of water-erosion.

The mudstones, and pyroclastic rocks have a varying degree of resistance to erosion. Strongly resistant bands, forming well marked outcrops, may often be traced for some distance, others die out rather irregularly. The map, in this region, does not pretend to have more than a general accuracy.

The mass on Cleary's Hill, which is taken to represent the base of the series, owes its great width of outcrop, not to its thickness, but to the fact that it slopes down the face of the hill. A certain amount of faulting occurs where Cleary's Gully debouches on to the Common, which makes estimates of thickness in this region very unreliable.

A second occurrence of the Baldwin Agglomerates is indicated by the rocks west of the limestones in Spring Creek, forming the ridge between the Manilla and Moore Creek roads. Here the coarse conglomeratic character has quite disappeared; the rock is merely a breccia, of medium grain-size, and the interbedded mudstones greatly predominate over the pyroclastic rock. The several bands of the agglomerate occupy the whole of the western part of the Tamworth Common, and, on the extreme west, are bent into an anticline. This anticline may be traced northwards to Moore Creek, but becomes rather flattened out. While much of the material in the agglomerate in this region, may have been derived from the centre of eruption near Cleary's Hill, there was evidently another point of eruption towards which these rocks may be traced,

which is indicated by the prominent hill in Housefield's Selection, Portion 120, Parish of Woolomol. This consists of coarse bouldery agglomerate, the inclusions of which are similar to those on Cleary's Hill, and are so rounded as to resemble even more closely, normally waterworn pebbles, and these are abundant in the upper portion of the mass which is at least 200 feet thick, and is free from interstratified mudstones. North of the hill is a small dyke of keratophyric quartz-felpar-porphyry, fragments of which also occur in the agglomerate.

The horizon of the Baldwin Agglomerates seems to be represented south of the Peel River by the mass of agglomerate, that runs through the eastern corner of the town of West Tamworth, and through portion 27, Parish of Calala, as well as by a band of tuff in the valley of Goonoo Goonoo Creek, portions 15 and xx. Evidently the agglomerate has greatly thinned out in this direction. No continuation of the great mass of agglomerate that comes down to the north side of the river, at the Two-Mile Bridge, can be traced on the southern side; which is a further piece of evidence in favour of the view, that the Peel River alluvium conceals an important fault.

The line of junction between the Middle and Upper Devonian claystones and mudstones is quite an indefinite one, when there is no intervening development of agglomerate, as is the case with the majority of the boundary line drawn through the Parish of Woolomol. This line is, therefore, almost entirely arbitrary, and was drawn merely by reference to the occurrence of the limestone on the east and agglomerate on the west. The claystones of the Middle Devonian Series, when they have not been silicified into cherts, can rarely be distinguished from those of the Upper Devonian Series. There is probably a fault between the limestones and agglomerates in sections 41 and 44 respectively of the Parish of Woolomol, as they are much closer to one another than would be otherwise possible.

Above the agglomerates, extend the monotonous series of thick claystones, and mudstones, occasionally radiolarian, interstratified with some tuffs, just as has been described for the Barraba Series

in previous papers. These occur typically in the south-western corner of the area shown in the map herewith. The fossils of this zone, apart from the radiolaria, which may occur in the tuffs as well as the claystones (see **10**) are confined to *Lepidodendron australe,* and fluted stems like Calamites, just as occur in the rocks of the Upper Middle Devonian Series.*

These fossils are particularly abundant in the gully traversing portion 59, Tamworth, "Porter's Gully" of the previous authors, where they occur in the mudstones that are interbedded with the Baldwin Agglomerates. They are fairly common elsewhere in this association. It remains to add that intrusions of felspathic tuff into the Upper Devonian mudstones, show just the same features as are exhibited in Figs. 9-12. Not infrequently the material of the tuff has been more or less impregnated with prehnite.

Tectonics of the Devonian Series.

It is now possible to summarise the main tectonic features, discovered by tracing such stratigraphical horizons as the district affords. For the central feature, there is the well-marked elongated pericline, the axis of which runs in a north-westerly direction up the valley of Seven-Mile Creek. Northwards, this is followed by close-packed anticlines, and "schuppen"-strips, extending to Moore Creek. Southwards, there is an interruption in the strike marked by the Cockburn River syncline, which has a north-easterly strike; and a parallel anticline to the west of it, the axis of which crosses the railway-line near the Nemingha platform. The Seven-Mile Creek pericline is thus the result of intersecting folds. South and east of this are the close-packed folds and "schuppen" fault-strips, that form the greater part of the Parish of Nemingha, and occur with even greater intensity of disturbance east of the serpentine.

* With regard to the remarks of the previous authors(**9**), concerning the downward range of *Lepidodendron*, nothing has yet been found to invalidate their conclusions. No *Lepidodendron* has been found at a horizon that can be proved to be lower than that of the Tamworth-Moore Creek Limestones, but some Lepidodendra, that occur in Loder's Gully, and in the railway-cuttings east of the Nemingha Siding, must be very close to the horizon on which the Moore Creek limestone would occur, if it were developed in this region.

Westwards from the pericline, the series continues with a south-westerly dip and decreasing inclination. There are probably one or more faults running to the west of the Igneous Zone, causing repetition of it. Again, there are the faults in the Tamworth Common, at Cleary's Hill, and at Spring Gully, which seem to extend to Moore Creek. These have a roughly meridional direction. The strata, however, do not follow this direction, but swing round to the north of the Tamworth Common, till they are dipping due south. This bend possibly represents the edge of another syncline with a N.E.-S.W. axis, of which the south-western limb has been cut off by the fault in Spring Creek valley. The strata to the west of this fault are flattened out, and are bent into a syncline, which can be traced northwards to Moore Creek, and southwards across the Peel River. Its axis runs in a direction trending N.N.W. to S.S.E.

Recognisable zones, wherever they have been found, are seen to have been repeated by faulting, and it is safe to assume that more strike-faulting must be present undiscovered in the monotonous series of mudstones and tuffs in the Upper Middle Devonian, and the Upper Devonian Series. The rarity of faults in the sections exposed in the railway-cuttings should, however, warn one against over-estimating this feature.

In addition to these roughly meridional faults, there are others which are more nearly parallel to the axis of the Cockburn River (and Tamworth Common ?) syncline. Thus there are two directions of folding and faulting in the district, with some lines following an intermediate direction. The question as to the relative age of the two at once arises. There is not yet, however, sufficient evidence to show the nature of the thrusts and movements that have brought about this reticulation of tectonic lines. In adjacent districts now under investigation, a different intersection of tectonic lines is observable, and, until more is known of these areas, a discussion of the tectonics of the region would be premature.

Thickness of the Devonian Series.

The facts recorded in the foregoing paragraphs show that the attempt to find definite continuous horizons, from which the tec-

tonic structures and the thickness of the formations involved might be exactly determined, has been in a large degree unsuccessful. It has, however, been proved that some faulting is present, producing a greater degree of repetition of strata than was assumed in the previous estimate of the total thickness of the series, though the thickness of the individual beds of limestone, claystone, and tuff, and the total apparent thickness, were measured with great care. As yet, however, it is quite impossible to determine the exact amount which must be deducted from that total (9,260 feet). Plotting the old line of section on the new map, we find that the lower portion of the Baldwin Agglomerates on Spring Creek was included in the earlier total. The agglomerates here are as finely granular as much of the pyroclastic matter in the Middle Devonian Series, and they would naturally be classed with the latter, before detailed mapping had shown their connection with the deposit of large boulders on Cleary's Hill. To obtain the total apparent thickness of the Devonian rocks in this district, we must, therefore, add the remainder of the Baldwin Agglomerates, about 1000 feet and the thickness of the Barraba mudstone, *apparently* about 2400 feet. The columnar section given in Fig. 1 shows the relative thickness of the various subdivisions of the Devonian Series as far as can be ascertained at present.

Conditions attending the formation of the Radiolarian Rocks.

As this district is frequently cited as a classical example of the development of a series of radiolarian rocks in comparatively shallow water, the subject should not be passed over in the present communication; but, as further studies are in progress in adjacent areas, where similar rocks are developed, and much remains to be investigated, we will merely note the bearing of the new observations on the views of the authors who studied the question here previously. According to them, the radiolarian rocks "were deposited in clear seawater, which, though sufficiently far from land to be beyond the reach of any but the finest sediment, was, nevertheless, probably, not of very considerable depth"(9). This conclusion was based on the following considerations:—(1) The presence of ripple-marking, (2) the abundance of plant-remains indicating the

proximity of land, (3) the absence of any coarse terriginous sediment, and (4) the intercalation of coral-limestones. The present writer concurs entirely with these conclusions. The only consideration which gave rise to some doubt was the possibility that the Baldwin Agglomerates, now proved to be interstratified in the radiolarian series, might owe the rounded character of their inclusions to water-erosion. The present study, however, tends to the conclusion, that, even if this were so, as seems possible in some cases, this would not indicate the presence of a persistent coastline, but only the development and rapid destruction of islands, which were the summits of masses of agglomerate erupted from vents in the flat floor of the sea. The development of the Baldwin Agglomerates marks an epoch when such great eruptions were in progress. It is not yet clear that the building of volcanic islands characterised the eruptions, that produced the Igneous Zone in the Middle Devonian Series. The eruptions may have occurred at a considerable distance from a persistent coastline. Except for the products of these great eruptions and the many minor convulsions, the sediments are of the finest grainsize, and largely composed of the remains of radiolaria. The depth of the sea in which they were laid down, must have been sufficiently great to give the overburden requisite for the production of intrusive tuffs, and sufficiently shallow to permit of the formation of ripple-markings, and coral-reefs. The exact depth at which this balance was obtained cannot be estimated with any precision. Doubtless it varied somewhat, as the presence of definite zones of limestone would lead one to infer; but as the radiolarian rocks, with interbedded and intrusive tuffs, adjacent to the limestones, are quite similar to those elsewhere in the series, there is no reason to assume that these variations were large. We may, perhaps, conclude that there is no evidence that the radiolarian rocks were formed at a depth less than the maximum at which it was possible for the limestone to have been formed. The work of Darwin, Dana and many others has shown that the reef-building corals in the modern seas, do not live at greater depths than about fifteen or twenty fathoms, though certain isolated forms extend much further down. The corals of the past seem to have

had the same general range. [The evidence for this statement has been recently summarised by Grabau(21)].

Serpentines, etc.

As in the areas described in former papers, the serpentine follows the line of fault, which separates the highly disturbed rocks of the Eastern Series, from the less crumpled rocks, which lie to the west. The band of serpentine varies greatly in width. At the southern end of the map, on Nemingha Creek, it is not more than 50 yards across, and is even narrower a short distance to the north. It is much broader at the head of Spring Creek, being nearly 300 yards wide there, and then tapers gradually northwards, dying out completely in Portion 144 of Nemingha Parish. The fault-line may, however, be traced into Portion 169, where there is a small lenticular area, about ten yards long, composed of ferruginous carbonate rock, such as represents the serpentine in other portions of the Serpentine Belt, as in the Nundle and Crow Mountain districts.

The serpentine is mostly of the sheared, chrysotilic variety; some massive bastite-serpentine is present, and a little antigoritic rock. Other alteration-products are rare. A chalcedonic replacement of bastite-serpentine occurs in Portion 176, and opal, with dendritic markings, in Portion 129. Near this was found a small patch of olivine-gabbro, only a few yards in extent. The felspar of this rock was converted partly to saussurite, and partly to clinozoisite. Small segregations of chromite occur in the serpentine. With this, hyalite has been found by Mr. D. A. Porter(4).

In several places there are abundant intrusions of a porphyritic or massive dolerite in the serpentine. This rock has exactly the same characters as that occurring in a similar situation in the neighbourhood of Bowling Alley Point(17.p.156). The individual masses are quite small, ten or twenty yards long, and about half as wide. Some are rather sheared. None appear to cut the serpentine transversely, but the individual masses may be fragments of larger instrusions torn apart by movements in the body of the serpentine. No dolerites of this character have been found outside of the serpentine.

The tectonic features of the serpentine-intrusion differ from those normal elsewhere in the Serpentine Belt, in the sudden bending of the serpentine into a north-north-easterly direction, where it approaches the granite. That this is not due to the wedging outwards of the strata by the invasion of the granite, is shown by the fact that the strike of the Devonian rocks continues almost unchanged, and is cut obliquely by the serpentine. We may, perhaps, see in this some evidence that the stresses, which determined the Cockburn River axis of folding, had begun to make their influence felt when the intrusion of the ultrabasic rock occurred.

Moonbi Granite.

About fourteen square miles of the area covered by the present map are occupied by granite. This is the southern extremity of a batholith which extends from Bendemeer to the north, in the direction of Attunga, to the north-west. According to Mr. E. C. Andrews(**12**), it is invaded by the more acid granite of Bendemeer, which forms resistant masses that stand out in relief above the more basic Moonbi granite. On the east, the granite is bounded by the jasperoid rocks of the Eastern Series, which, also have a high relief, and form the prominent peak of Bullimballa (Black Jack), about six miles to the N.N.E. of Moonbi. Both these prominences are, however, outside the limits of the area under discussion.

The granite is of coarse or medium grainsize, even-grained, or slightly porphyritic. It is fairly potassic, containing a considerable amount of orthoclase and biotite. Hornblende is the dominant coloured constituent, and sphene is generally present in notable amount. Mr. Andrews has compared this granite with the sphene-granite-porphyries of northern New England, to which he attributes an early Mesozoic age(**12**).

The granite is invaded by a variety of vein-rocks; aplites, with druses containing crystals of quartz with a mica like zinnwaldite, occur associated with veins of quartz bearing small amounts of molybdenite, in the high ridge between the Cockburn River and Moore Creek. Various types of pegmatite, either graphic quartzose pegmatite, or more richly felspathic rocks, often containing a little

tourmaline, are to be found near the Kootingal railway-station, and a beautiful garnetiferous, and graphic tourmaline-aplite, is developed on the travelling stock-route, in the north-eastern corner of the Parish of Tamworth. Dykes of finely granular rocks of intermediate composition are found, and are best described as microdiorite and micromonzonites, or diorite and monzonite aplites; and a peculiar lamprophyre, which has the mineralogical composition of an augite-minette, and contains spherulites of quartz and felspar. A few dykes of pegmatite and quartz-porphry extend from the granite into the surrounding Devonian rocks, but only for a short distance. This absence of an extensive series of dyke-rocks is a characteristic feature of the Moonbi granite.

The metamorphosing effect produced by the granite on the surrounding rocks has been considerable, and is especially noteworthy in the limestones, and the pyroclastic rocks. In the latter, it generally has the effect of causing the augite to change into the stable actinolite, rather than into chlorite, the ilmenite is replaced by sphene, and the felspar is recrystallised, sometimes as a mosaic of minute, indeterminable, untwinned grains, and sometimes in clear crystals of andesine. In the more altered types, abundant tiny plates of biotite are formed, the calcite in the vesicles, or irregularly distributed throughout the rock, passes into garnet, and, still more rarely, some secondary pyroxene is developed at the expense of the amphibole. These rocks are best developed in a railway cutting east of Tintinhull, while the most altered garnetiferous types occur in Portions 113, 123, and 169, Parish of Nemingha. Rocks with secondary pyroxene also occur in the north-eastern corner of the Parish of Tamworth. Associated with the garnetiferous rocks in Nemingha, are massive hornblende-schists, representing former dolerites, and garnetiferous hornblende-schists, that were, in all probability, amygdaloidal spilites. The hornblende-schists, which extend southwards from Portion 157, and those occurring in Portions 42, 63, and 64, Nemingha, are probably also altered spilites. The zone of alteration of the igneous rocks varies somewhat in width; generally, it is about a quarter of a mile across.

The zone in which alterations of the limestone are recognisable is less extensive. The limestone in Seven-Mile Creek is greatly altered within a furlong of the granite, but, beyond that, it is unchanged or merely recrystallised, with the partial obliteration of the fossils. In the more altered parts, the limestone is changed to silicates such as garnet, wollastonite, diopside, and vesuvianite; but sometimes traces of the fossils are preserved among them, as noted by previous authors.

In the Parish of Nemingha, the limestones are much less altered. All the fossils have been obliterated near the granite, but comparatively little silicate-mineral has been formed. Where, however, the limestone was originally mixed with tuffaceous material, there are druses filled with calcite, epidote, and vesuvianite; and in the adjacent, often quartzose, tuffs there are regenerated felspars, with diopside and garnet. These druses, doubtless, represent original inclusions of limestone in pyroclastic rock.

The clayslates and cherts show least sign of alteration. The metamorphic zone extends barely 100 yards from the boundary of the intrusion. The most altered rocks are those which form the small patch of sedimentary rock that is completely surrounded by granite; this occurs in Portion 76, Tamworth. These consist of a highly crystalline, biotite-schist, containing veins and knots of granite and pegmatite. Less altered schists occur at the foot of the hill in Portions 42 and 64, Nemingha, and in Portions 178 and 183, Tamworth. Generally, however, the contact of the sedimentary rock and the granite is hidden by drift. The greater part of the boundary, as plotted on the map, was obtained by linking up isolated exposures of the contact-line, seen here and there in creek-beds.

The form of the granite-mass calls for comment. The previous authors showed that the margin of the granite in Seven-Mile Creek is concordant with the strike of the sedimentary rocks, and stated that the latter dip *beneath* the granite, which, they accordingly suggest, is of the nature of a laccolite(9). While unable to confirm this observation, the writer finds that the constant dip of the sediments *towards* the granite is a marked feature of its western mar-

gin, and certainly suggests that the limits of the granite-intrusion may have been determined by the tectonic structure of the invaded rocks. It seems quite clear, however, that the granite, if laccolitic, did not extend far over the Seven-Mile Creek anticline. The rocks that form this structure are very little altered, while the rocks, which, in Erdmannsdörfer's view(**24**), are to be regarded as the Devonian and Carboniferous rocks altered by the overlying laccolite of the Brocken granite, are the highly altered series, that form the Eckergneiss.*

The southern margin of the granite is quite transgressive. It seems to be no more than a coincidence that part of it is approximately parallel to the axis of the Cockburn River syncline, for elsewhere it cuts right across the axis, and also across the several repetitions of the Lower Middle Devonian Series, the Serpentine Belt, and invades the Eastern Series. Hence we may conclude that the folding of the Devonian rocks, both along the main structural N.N.W.-S.S.E. axis, and the subsidiary N.E.-S.W. axis was accomplished before the intrusion of the granite occurred. The absence of any noteworthy gneissic structure along the margin of the granite is also evidence towards the same conclusion.

Tertiary Basalt.

A small plug of basalt occurs on the western edge of Portion 83, Parish of Woolomol. It is roughly oval in shape, and about sixty yards long. It does not give any noticeable relief. The rock is granular or aphanitic, with small crystals of olivine, and is massive or slightly vesicular. The microscope reveals the presence of cognate xenoliths of olivine, pyroxene, and picotite, and very interesting vesicles filled with natrolite and opal, which seem to be of primary origin. In general character, the rock is quite analogous to the majority of the Tertiary basalts in other parts of the State.

Terrace-Gravels.

On either side of the Cockburn and Peel Rivers, may be seen terraces of gravels lying thirty or forty feet above the present

* Goldschmidt, however, doubts the possibility of such gneisses being produced under so small a pressure as Erdmannsdörfer assumes(26).

flood-plain. The best examples of these are the gravels south of the Cockburn River, near Kootingal railway-station, which are exposed in the road-cutting by the Public School. A large terrace covered by gravel, also occurs on the point between the Peel River and Goonoo Goonoo Creek, in Portions 15 and 21 of Calala Parish, and smaller masses at other points, *e.g.*, by the railway-viaduct at West Tamworth, in Portions 1 and 30 of Calala Parish, and north of the Peel River by Nemingha railway-platform. These consist, for the most part, of pebbles of jasper and quartz, with a binding of clay and red loam. Scattered pebbles of rocks of the Eastern Series can be found in several other spots, and doubtless represent other terraces, now more or less destroyed. Practically all the pebbles in the terrace-gravels have been derived from the Eastern Series.

Drift.

The masses of drift have not been separated from the terrace-gravels in the map, though they are a noteworthy feature in the agricultural geology of the district. We may distinguish stream-drift, the material brought down and deposited in an irregular manner, by the tributaries of the main rivers, and superficial drift, flanking the bases of the hills and accumulating through general soil-creep, etc., and, generally, any widespread deposit not flood-plain alluvium, which completely hides the underlying rocks.

The stream-drift deposits are well seen in the valleys of Nemingha and Gap Creeks, in the south of the Nemingha Parish. The latter has entirely filled its valley, and does not debouch as a single stream; the former had also a wide distributary area, but has recently been confined to a single channel. Spring Creek, by the serpentine, has also a great accumulation of detritus; and isolated patches of gravel, high above the present creek, as on Portions 70 and 85, indicate where the older stream-drifts of this creek joined with the terrace-gravels. These drifts cover the western margin of the serpentine to a great extent. To a combination of stream-drift and soil-creep is due the great thickness of gravel and soil along the foothills of the range behind Tamworth, and, in particular, that between Long Gully and Cleary's

Gully. Again, the drifts covering the margin of the granite in the Parish of Woolomol have this conjoint origin. The very large amount of drift at the present head of Seven-Mile Creek has been preserved in its present position by the capture of the headwaters of this stream, which now flows northward as Daruka Creek, to join Moore Creek. It is probable that the broad areas of drift that form the central part of the Parish of Woolomol similarly owe their preservation to the capture of their parent-stream, of which the headwaters are known as Levy's Springs, by Spring Creek, which runs through the Tamworth Common.

Where the drift is entirely derived from mudstones, it decomposes into a clay suitable for the manufacture of bricks. The clay-deposits of this character at West Tamworth are more than twelve feet thick.

A considerable thickness of stream-drift lies below the alluvium of the flood-plain of the Peel River. From records in the Department of Public Works, kindly placed at the writer's disposal by the Chief Engineer for Railway Construction, it is to be seen that the bed-rock of the Peel River valley at the railway-viaduct lies at a depth of forty to fifty feet below the present land-surface. The basal portion of the drift consists of from two to four feet thick of clay, which is covered by clay, gravels, and drift up to a thickness of twenty-four

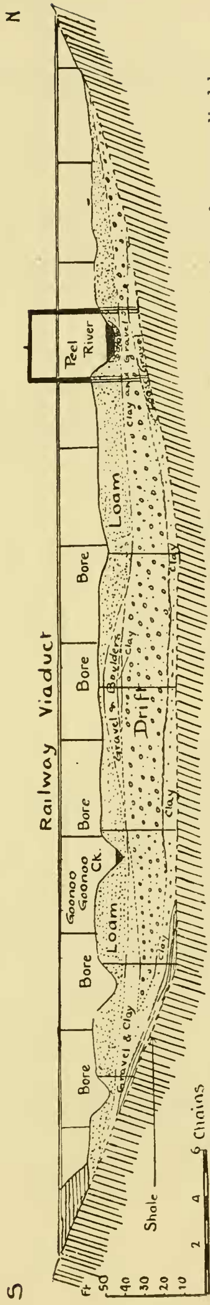


Fig. 14.—Section showing the alluvial deposits in the valley of the Peel River at Tamworth, from data supplied by the State Department of Public Works.

feet, with a bank of gravel and boulders in the centre of the valley ten feet high above this. (See Text-fig.14).

Alluvium of the Flood-plain.

The broad flood-plain of the two rivers is covered with a soft, black loam, of great agricultural value. In places, it is more than a mile wide, and is of varying depth, generally ten to fifteen feet. This is the depth of the soil by the railway-viaduct.

PETROLOGY.

The following notes are based upon a study of about two hundred thin slices of rocks from the Tamworth district, of which seventy came from the collections of the New South Wales Geological Survey, and of the University, and were those used by Messrs. David, Pittman, and Card, in the preparation of the previous paper on this area. Attention has been devoted chiefly to the igneous rocks; the sedimentary and metamorphic rocks show a much smaller range of interesting features. The chronological order has been followed as far as possible in the sequel.

Eastern Series.

The basic rocks of the Eastern Series are spilites, vitrophyres, and hornblende-schists, the product of the contact-metamorphism of the spilites. The spilite, which crosses the head of Spring Gully, south of Portion 189, Nemingha, has a poorly developed ellipsoidal habit, is massive or slightly sheared, and of fine grain-size. It has a well marked subvariolitic structure (1354). The felspar has been largely changed to epidote, the remainder is glassy, and frequently untwinned; it is probably albite. The pyroxene is changed to chlorite, or remains quite fresh. It is a colourless diopside. Magnetite-crystals occur in abundance. There are small veins of epidote, quartz and chlorite. A completely epidotised rock was found by Mr. Aurousseau, as a pebble in Spring Creek, doubtless derived from the Eastern Series. It is very like the Pre-Cambrian spilitic dolerite, from Tayvallich,

in Argyllshire, which was described by Dr. Flett(41), a specimen of which was kindly given to the writer by Dr. H. H. Thomas (a slice from specimen 13218 of the collection of the Geological Survey of Great Britain.) The preservation of the subvariolitic structure in the epidote is very distinct.

The amphibole-schist, derived from the metamorphism of the spilite, which occurs in Portion 155, Nemingha, is considerably decomposed (1338). The original structure has been entirely lost, and the large grains of plagioclase have been replaced by finely granulated albite, while the remainder of the rock consists of matted chlorite and actinolite, dotted with minute grains of titanomorphite. Another form of altered spilite occurs in the northeastern corner of the area mapped in Portion 64, Nemingha(1323). It has completely lost its original texture, and has now the habit of a fine-grained amphibolite. It consists of a mosaic of interlocking grains of untwinned albite, actinolite scattered irregularly in isolated prisms or sheaf-like aggregates, and a little irregularly granular sphene, sometimes in small clusters. A few prisms of apatite are also present. Slide 1305, from the same locality, is probably an altered vesicular magnetite-quartz-keratophyre-tuff. It is a strongly schistose rock (see Plate lii., fig. 1). The grey, dusty, felspathic groundmass is too minutely granular for determination. It is sprinkled with small isolated prisms of hornblende, and well formed crystals of magnetite, evenly though not densely distributed throughout the rock. Interlaminated with the grey felspathic portions, or forming fragments in it, or apparently filling vesicles, is a mosaic of quartz-grains, with abundant prisms of actinolite. The rock has been so cut by "schuppen" shearing, that the form of these has been largely lost. They perhaps result from the recrystallisation of interlaminated and fragmentally included sedimentary material, and the infiltered infilling of vesicles.

The vitreous rock from Pine Hill (1119) has been described above (p. 547). It is more acid than most of the other rocks of spilitic suite in the Eastern Series.

Igneous Rocks in the Middle Devonian Series.

These rocks include many types of dolerite, spilite, and keratophyre, and the pyroclastic rocks, as well as the metamorphosed equivalents of these.

The dolerites differ from one another in texture, the composition of the felspar, and the nature of the pyroxene. The quartz-dolerite, which forms a very small mass in Portion 110, Nemingha (1132), is characterised by the presence of basic andesine or labradorite as the dominant mineral, as is also that which occurs near the magnetite-keratophyre in Portion 175,(1107, 1128), and that which invades the porphyritic spilite on the northern end of East Gap Hill (see Text-fig. 4). These rocks have a granitoid texture, the felspar-prismoids, being approximately idiomorphic, and often strongly zoned. The augite is of the normal character, slightly decomposed, and possessing a large optic axial angle. Quartz occurs in large grains, or in granophyric intergrowth with felspar. Ilmenite is abundant, and apatite rare, though some large prisms occur. The chemical composition of 1132 is given on page 74a; the composition of the felspar calculated from this would be $Or_7Ab_{47}An_{49}$, or, reckoning orthoclase as albite, $Ab_{52}An_{48}$, which corresponds with the result of the optical determination. The dolerite on the north of East Gap Hill contains some highly granophyric masses, while there is also some uralitised albitic dolerite, from Portion 204, Nemingha, which cannot be distinguished macroscopically from the adjacent calcic variety.

The porphyrite, which occurs in Portion 158, Woolomol(1162), is rather different from these. This is so free from any sign of contact-metamorphism, though within the zone of altered rocks, that some doubt must remain, as to whether it is really coeval with the Devonian doleritic series. It is, however, quite unlike any Tertiary basic rock known to the writer. It has a fine-grained base, consisting of prismoids of andesine, with chlorite replacing augite, titanomagnetite, a very little quartz and apatite. The phenocrysts are sometimes as much as 3 mm. in diameter. They consist of plagioclase, with zones of liquid inclusions, and have commenced

to decompose. Its composition, determined from the Carlsbad-albite twin by means of Professor Becke's diagram,* is $Ab_{60}An_{40}$. The phenocrysts of augite are generally rather smaller, have a large optic axial angle, and are decomposed on the periphery.

Dolerites also occur with albite as their felspar, and of these there are two main groups, the granitoid and the poryphyritic. Rock 1120, which occurred adjacent to the rocks with basic felspars in Portion 175, Nemingha, is like them in texture and grain-size. The felspars are fresh and dusty, are slightly zoned, and have the composition of albite-oligoclase. They are almost idiomorphic, and are surrounded by a micrographic intergrowth. The pyroxenes are almost completely changed to chlorite, ilmenite is abundant, and quartz appears in a few separate grains, as well as in the intergrowths. A few large grains of apatite occur, but these are not present in the intergrowth. From its textural identity with the calcic rocks of the district, it seems possible that this may have been derived from such rocks by albitisation. Other albitic rocks are represented by slides 1024, 1030, 1039, 1048, 117 occurring respectively with porphyritic spilites at Tintinhull (Portion 123, Tamworth), in Portion 202, Nemingha, with spilites at Pullman's Hill, Portions 205, 48, Nemingha, in Portion 204 (the northward continuation of the belt of calcic dolerite which invades the porphyritic spilite of East Gap Hill), and in Portion 181, at the southern end of West Gap Hill, associated with pyroclastic rocks. The first four of these occur about half a mile from the nearest outcrop of the granite, and there is no definite evidence of contact-metamorphism. The plagioclase is clear, and very little, if at all, spongy. Quartz-grains occur in small amount, but there is no granophyric intergrowth. The ilmenite has been more or less converted into titanomorphite.

The porphyritic dolerites of Tintinhull have already been briefly described. They are sometimes aphanitic, with small often reddish phenocrysts of felspar (1138, 1160). This is a water-clear albite,

* As yet unpublished, but in use in the laboratory at Vienna, during the writer's visit in 1914.

quite idiomorphic, and either isolated, or associated in glomero-porphyritic aggregates, which are sometimes in ophitic relation to pseudomorphs after pyroxene. The original pryoxene phenocrysts were small and not abundant, and are now completely uralitised. The groundmass is very fine-grained, sometimes massive, sometimes with a strongly marked flow-structure, in which there are small string-like accumulations of magnetite. The constituent minerals of the groundmass are minute laths of clear felspar, amphibolitised and chloritised granular pyroxene, and magnetite. Epidote occurs with quartz in the vesicles, which are often abundant. Secondary silicification sometimes has replaced more or less of the felspar-phenocrysts (as in 1138), and veins of quartz may traverse the rock. Small accumulations of dusty hæmatite are not uncommon. The rock of Pullman's Hill, 48 Nemingha, is quite similar to the above, showing a good flow-structure (1130). Its chemical composition is given on p.602; the composition of the felspar calculated from this analysis is $Or_4 Ab_{66} An_{40}$, or $Ab_{64} An_{36}$, which is rather more basic than the composition determined by optical measurements. This discrepancy, no doubt, arises from the presence of chlorite and epidote in the base. The spilite in the eastern side of Portion 65, Nemingha, is similar to the above (1150), so much so that there can be no doubt that it is really a portion of the same rock-mass separated from the Tintinhull and Pullman's Hill spilites by folding and faulting. As remarked, the structure of these rocks is very similar to that shown by the porphyritic spilites in the Eastern Series in the Nundle District, and is sufficiently illustrated by the photomicrograph already given of that rock. (See (**17**), Plate xxv., fig.3).

Associated with these rocks, and apparently passing into them, is a less finely granular albitic rock, which shows the typical sub-variolitic spilite-texture, and has finely crystalline margins about quartz-filled vesicles. Its pyroxene has now been completely uralitised(1166). The albite-dolerite already described (1024) is in similar association with the spilites at Tintinhull.

The porphyritic spilites of East Gap Hill have the same mineralogical features as those of Tintinhull, but differ in grain

size. If they be a portion of the same rock-mass as the Tintinhull rocks, as seems very probable, the conditions of consolidation must have been different. The porphyritic spilites on East Gap Hill are very coarsely granular, where they are invaded by the dolerite near the summit of the hill, and diminish in grainsize, and increase in vesicularity as they are traced to the south. The more coarsely granular types contain large phenocrysts in a subvariolitic groundmass (1032, 1033, 1168). The phenocrysts are idiomorphic plagioclases, but are moulded on augite, when the two minerals come into contact. They may be as much as 8 mm. in length. It is difficult to determine their composition, as the crystals are rather dusty, and full of partially chloritised zonary inclusions of the groundmass, and of epidote. They seem to be albite, however. They are not zoned, and have been more or less replaced by a mosaic of minutely granular quartz, which may, in some cases, leave only the outer rim of the felspar intact. Phenocrysts of augite also occur, either singly or in aggregates. They are rather decomposed, and may include large grains of magnetite. Some octahedra of magnetite also form phenocrysts. The groundmass consists of lathy oligoclase with forked microlitic extensions, skeletal forms of ilmenite, as well as definite grains, and small grains of titanomorphite. The pyroxene, which was originally in the form of small prisms, is now completely changed to chlorite and epidote. Irregular patches of secondary quartz-mosaic also occur in the base. The vesicles are numerous, and differ in their content of minerals. The following types have been noted:—

(*a*) Outer margin, epidote; central portion, orthoclase.

(*b*) Outer margin, epidote and chlorite; inner portion, quartz.

(*c*) Outer margin, epidote and chlorite; inner portion, quartz-mosaic.

(*d*) Outer margin, epidote; central portion, chlorite.

(*e*) Outer margin, epidote; inner portion, chlorite; centre, epidote.

(*f*) Epidote, chlorite and axinite, irregularly arranged.

(*g*) Epidote, chlorite, felspar and axinite.

The southern end of this mass is very fine-grained, and exceedingly vesicular, and passes without any definite break into the mass of pyroclastic rocks that are described below.

A single sill of spilitic dolerite invades the clayslates, at the Municipal Quarry in the Tamworth Common. It is a rock of medium to fine grainsize, with a subvariolitic texture(1018). The felspar is clear albite, with a few inclusions of chlorite. It forms long plates with occasional skeletal extensions. Intersertally are minute laths of felspar, and a small amount of granular quartz, mixed with a considerable amount of chlorite. Many small, brown grains of augite occur, together with a few larger ones, which are fairly fresh. There is also a little magnetite. Some secondary carbonates are present.

Specimen 1303, which represents what is probably a small intrusion in Portions 213 and 216, Nemingha, is a most interesting rock. In hand-specimen, it seems to be a normal but rather decomposed dolerite, with large augite-phenocrysts. The microscope shows that its constituent grains are mostly shattered. The phenocrysts are large, zoned augites, similar to those occuring in certain andesites and porphyrites. The edges of the broken fragments of them are quite sharp, and show no sign of resorption. Generally they are yellow-brown or green, and are markedly pleochroic. Frequently adhering to these crystals are fragments of green partially chloritised glass, containing laths of acid plagioclase and spherulites of chlorite. This adheres only to the crystal-edges of the augite, it is not found against the fractured edges. The fragments of crystal and glass alike are embedded in a groundmass, which consists of irresolvable, apparently partly felspathic decomposed matter, which seems to have been produced by the pulverisation of felspar-phenocrysts, together with fragments of pyroxene, chlorite, epidote, calcite, and rarely a little magnetite. This rock is best considered as a brecciated, hypocrystallite augite-porphyrite. (See Plate lii., fig. 2.)

Keratophyres.

These are far less frequent in the massive condition than the spilites or the dolerites, though they are very abundant in the

pyroclastic rocks. The largest development is in the complex on Portion 175, Nemingha. They generally contain some quartz. Two types may be specially noted. Specimen 1140 resembles the rocks from Pipeclay Gully, near Bowling Alley Point(17). It is vesicular, with phenocrysts of albite, in a base of finer laths of felspar, and a small amount of quartz with chalcedonic margins. Chalcedony also occurs surrounding the grains of quartz. It is probably intermediate in composition between the porphyritic magnetite-keratophyres and the spilites. The first-named are the more coarsely crystalline. Their large phenocrysts are all albite, or are partly replaced by calcite, and a mosaic of minute prisms of albite; which certainly suggests the secondary nature of the albite. They are also dusted with other secondary material. There are, in addition, large octagonal areas of calcite and chlorite, which doubtless represent former phenocrysts of augite. A few of these have inclusions of felspar. The base consists of minute laths of acid plagioclase, chlorite, and magnetite, the latter occurring abundantly interstitially, and especially segregated about certain lines, as in 1148, and about the calcite-filled vesicles. Specimen 1361 differs from the others in the finer grainsize, and in the absence of phenocrysts of augite, and also in the presence of a large amount of black inclusions in the margins of the felspar-crystals, which inclusions, however, do not seem to be of primary origin, but to have been introduced from the magnetitic matrix, and lie in the cleavage-traces of the felspar, and in other definite directions in the crystals that are not marked by any noticeable cleavage. These two rocks also afford evidence of the pneumatolytic introduction of magnetite, in the later stages of their consolidation.

Magnetite-keratophyre also occurs in Portion 110, Nemingha, in the southern extension of the East Gap Hill zone, but as it has some fragmental characters, it is discussed below.

Some quartz-keratophyres remain for consideration. One of these (1142) occurs in Portion 138, adjacent to the magnetite-keratophyre of Portion 110. It is porphyritic, with phenocrysts of andesine which fill the numerous vesicles. Dusty hæmatite is

present in small amount. Specimen 1148 is a fine-grained, vesicular, purplish-grey rock, with small, clear phenocrysts of albite, one of which contains, in its central portion, abundant inclusions of dusty magnetite. These phenocrysts have a roughly trachytic arrangement. The groundmass consists of abundant minute felspar-laths, sprinkled with finely divided hæmatite. Quartz is present in some amount, often chalcedonic, and a little chlorite occurs. There are abundant large vesicles filled with calcite, and chlorite, or quartz and chlorite. There is often a dense segregation of dusty magnetite around the whole, or only a portion of the periphery of the vesicles, and one can see that the zone of vesicles that are most abundantly surrounded by magnetite, corresponds to a zone of enrichment by magnetite of the main mass of the rock, which lies on either side of a narrow crevice, running transversely to the flow-direction of the rock. This is clearly illustrated in the figure given (Plate lii., fig. 3). The presumption is that the magnetite in the rock has been partly, at least, introduced pneumatolytically, and that surrounding the vesicles is due entirely to this method of deposition. This is in accord with the results obtained from the study of the Hyde's Creek complex in the Nundle District(17).

Rather different types of rocks, which, however, are clearly related to the above, are represented by specimens 1360 and 1363, that occurred in association with the agglomerate in the complex illustrated by Text-fig. 13. They were termed spilite-porphyrites in the foregoing. The felspar-phenocrysts may reach 2 mm. in length, are dusty and spotted with chlorite, slightly zoned, and show pericline- as well as albite-twinning. The augite phenocrysts are also large, 3 mm. × 0·5 mm. at most, are fresh or more or less decomposed, and have a large optic axial angle ($2V = 52°$). Magnetite also occurs in large well-formed crystals. The groundmass consists of lathy andesine-oligoclase, quartz in sharply defined crystal-grains, and but rarely intersertal, granular augite, and skeletal ilmenite, with small vesicles filled with quartz, chalcedony,

opal and chlorite. This rock is on the borderline between the quartz-dolerite-porphyrites and keratophyres, and, like the adjacent dolerite proper, it has not been albitised.

A more typical keratophyre is that occurring near Gap Creek, half a mile east of this spot (1136). Its composition is shown by the analysis given on p.602. Its texture is very net-like; there is no sign of flow-structure, though the ragged felspar-laths sometimes give a sort of ophitic texture with the small amount of augite, with which they are associated. The latter is now mostly changed to chlorite. The felspar also forms small, interstitial, spherulitic aggregates. Quartz is very abundant, both interstitially and in small veins, but there are no chalcedonic phases. The composition of the felspar, as calculated from the analysis, is $Or_3Ab_{80}An_{16}$, equivalent to $Ab_{84}An_{16}$.

In addition to this, there are a few occurrences of highly crushed quartz-albite-porphyrites, in Portions 168, 213, and 171, Nemingha. These consist (*e.g.*, 1326, 1332) of broken phenocrysts of albite (probably), with all the optical effects of great strain, and a groundmass of finely granular, and intergrown, strained quartz and albite. There is rarely also a little biotite in spangles and crystal-plates, wisps of fibrous, pale green actinolite, both in phenocrysts and base, and a little magnetite and titanomorphite. A similar rock occurs on the north side of Housefield's Hill, Woolomol, forming a vein in the Middle Devonian rocks. The whole appearance of these rocks strongly recalls that of the albitic veins in the serpentines near Bingara, and it is not clear whether they should really be classed with the Devonian keratophyres(**16**, p. 691).

Chemical Characters of the Spilite-Keratophyre Series.

The chemical features of these rocks will be illustrated by the following table, which should be compared with the tables given in previous parts of the series (**16**, p.704; **17**, p.139).

Chemical Composition of Middle Devonian Igneous Rocks.

	1132	1130	1136	A	B	C
SiO_2	49·96	50·17	71·52	72·51	56·06	52·88
Al_2O_3	15·49	15·56	11·76	13·10	18·36	21·25
Fe_2O_3	1·83	2·18	1·52	2·81	4·40	2·73
FeO...	10·85	12·06	3·44	0·90	2·68	3·02
MgO	4·70	3·49	1·18	0·20	4·58	4·93
CaO	8·52	7·77	2·72	1·84	6·06	7·40
Na_2O	2·90	4·12	5·05	6·76	3·71	3·95
K_2O	0·65	0·38	0·26	0·33	0·66	1·15
H_2O+	2·47	1·12	1·25	0·35	2·50	2·53
H_2O-	0·04	0·27	0·14	0·04	0·28	0·25
CO_2	0·05	0·21	0·38	0·76	0·24	0·20
TiO_2	1·40	1·51	0·28	0·31	—	—
P_2O_5	0·38	0·18	0·20	0·06	0·19	0 29
FeS_2 ...	0·10	0·10	0·12	—	—	—
Cr_2O_3	abs.	abs.	abs.	—	—	—
MnO	0·14	0·43	0·04	0·20	—	—
BaO	abs.	abs.	abs.	abs.	—	—
SrO...	abs.	abs.	abs.	—	—	—
	99·48	99·55	99·86	100·17	99·72	100·58
Analyst ...	W.N.B.	W.N.B.	W.N.B.	Radley	Mingaye	White

1132. Labradorite-dolerite, Portion 110, Parish of Nemingha.
1130. Albitic Spilite, Portion 48, Parish of Nemingha.
1136. Quartz-keratophyre, Portion 175, Parish of Nemingha.
A. Soda-granite-porphyry, Tayvallich, Argyllshire, Scotland(**26**).
B. Typical volcanic tuff, Tamworth(**9**).
C. Matrix of coarse volcanic agglomerate, Tamworth(**9**).

The discovery of calcic rocks in this area brings a feature into the discussion of the origin of the albitic rocks in this area, which was not present in the Nundle district; and some of the Tamworth rocks show the same microscopical features as those considered by various authors to indicate the secondary nature of albite in rocks of the spilitic suite, which features were not observable in the rocks described previously(**17**). As investigations are now in progress in the region between the Tamworth and Nundle districts, the further discussion of this question will be postponed till it be finished.*

* The writer has received, too late for consideration in the present paper, Dr. Nils Sundius' work, which deals with this problem. Geologie des Kirunagebiets. 4. Beiträge zur Geologie des südlichen Teils des Kirunagebiets. Vetenskapliga och Praktiska Undersökningar i Lappland. Anordnade af Luossavaara-Kirunavaara Aktiebolag. (Scientific and Practical Researches in Lappland, arranged by the Luossavaara-Kiirunavaara Aktiebolag.) Upsala, 1915.

Pyroclastic Rocks.

It is in this division of the igneous rocks, that the greatest difficulty arises, for they range from types scarcely separable from the normal massive rocks to those which are clearly tuffs, and agglomerates that closely resemble conglomerates. They also have a wide range of composition, corresponding to the range of variation in the massive rocks, and may include fragments of all the known types of massive rocks, as well as others, which have not been found forming separate masses; they may contain also fragments of all types of sedimentary rock in the district. This naturally makes a logical sequence in the description of these rocks almost an impossibility. It seems, therefore, best to divide between pyroclastic masses that are referable to one igneous type only, and those of a mixed composition. The latter can be divided according to their coarseness of fabric. Of these, some of the most coarsely fragmental types have rounded inclusions resembling boulders in conglomerates.

Of the rocks composed of a single type of material, we may, perhaps, take as an instance the augite-porphyrite breccia already described. It certainly is a passage-rock of a nature between massive and fragmental. A similar passage-rock is the spilite-breccia, which lies on the margin of the spilite-dolerite mass at Tintinhull. This rock consists of more or less fragmental phenocrysts of albite, set in a very fine matrix of the same character as that of the adjacent porphyritic spilite(1171). The brecciated quartz-keratophyres should also be mentioned here. Types occur, particularly in Portion 183, Nemingha, on West Gap Hill, which are even more fragmental than the highly strained keratophyres mentioned above. They have a grey quartzite-like appearance, and show small crystals of felspar, and have a more or less well marked bending. They consist of crystals of albite, irregular corroded quartz-grains, and sometimes fragments of a very fine-grained trachytic keratophyre, and aggregates of quartz and magnetite, drawn out into the general direction of the banding. The groundmass consists of the same material very finely divided. It is possible that these are flow-breccias(1052, 1125).

The pyroclastic rocks of the Igneous Zone on East Gap Hill extend down to Portion 138, and near their southern extremity, in Portion 110, is the fragmental magnetite-keratophyre mentioned above(1122). It, also, is possibly a flow-breccia. It is extremely patchy in constitution; adjacent portions are of different composition and texture; and the types of texture seen are usually different from those which are present in the magnetite-keratophyre-breccias at Hyde's Creek, near Bowling Alley Point. The groundmass of the rock is very like a sponge. The "sponge"-fabric is made up of fine laths of albite, clouded by kaolin, etc., and so darkened with abundant masses of minutely divided magnetite, that it is almost opaque. The interstices are filled with minute prisms of glassy albite, generally twinned, and accompanied by a little chlorite. Set in this matrix, are fragments of dense trachytic magnetite-keratophyre, with phenocrysts of albite and sometimes of fresh augite, and, in addition, there are fragments of normal trachytic keratophyre, with very little magnetite or augite. These inclusions vary from very minutely to coarsely crystalline types, and the latter may even be sufficiently rich in augite, to be classed as dolerites (Plate lii., fig. 4). A large vesicle present in the rock has been filled by a spongy mixture of albite and calcite. There can be little doubt that this rock has been affected by pneumatolytic solutions, which introduced the sodic felspar. The abundance of hæmatite, which gives the dominant red colour to the ferruginous pryoclastic rocks at the southern end of East Gap Hill, is probably also due to the action of these solutions, which have oxidised the magnetite in the magnetite-keratophyres. In those ferruginous keratophyres in which the iron ore seems to be of secondary, pneumatolytic origin, it is possible that the ore was deposited in the rock, in part at least, as hæmatite. In those, however, in which the majority of the iron occurs as magnetite, the dark grey colour is the characteristic feature. Of these, Specimen 1178 is typical. It has some macroscopical resemblance to 1122, but has very little groundmass. It consists of fragments of keratophyre, of which twelve different samples are to be found in a slice scarcely two square centimetres in area. These are closely fitted together, with a little cement made

of the material of the fragments finely comminuted. The following are the chief types of fragments present:—magnetite-keratophyres, varying in the amount of iron present, more or less trachytic, porphyritic, massive or hypocrystalline, the last being very vesicular; normal keratophyre, porphyritic or massive, trachytic, or with a wavy flow-structure and occasionally vesicular, coarsely crystalline albitite, partially porphyritic keratophyre-dolerite, etc.

The reddened rocks have usually a more ashy appearance, particularly on weathered surfaces. In 1330, the inclusions are mostly fine-grained trachytic keratophyre, with minutely granular augite, and a few more coarsely granular, non-trachytic types are also present. The base resembles that of 1122; it is very spongy, with a few phenocrysts of albite, and abundant secondary albite and chlorite filling the vesicles. In 1336, the same feature are present, but parts of the spongy or pumiceous matrix are free from iron-ore, but shade off irregularly into strongly ferruginous rock.

Hæmatitic breccias similar to these, but much more coarsely fragmental, occur on West Gap Hill. In these, there are large areas of finely divided prehnite and epidote. The matrix is rather spongy, a hypocrystalline confusion of felspar-laths, phenocrysts, and microlites, and abundant hæmatite. The inclusions are of various kinds of keratophyre; the most unusual of these has a texture resembling that of "rhomben-porphyry"; the others resemble those already described.

In addition to the red rocks of this character, there are others in which there is no base. The rocks consist entirely of fragments, which are sometimes half an inch in diameter, and are closely fitted together. These (*e.g.*, 1327) include keratophyre; prophyrite consisting of large rounded phenocrysts of acid plagioclase in a fine-grained subtrachytic base, in which are chlorite-filled vesicles; porphyritic spilite, the felspar albite, and the augite changed to chlorite; devitrified rhyolite with a well marked flow-structure; magnetite-keratophyre of varying character, sometimes extremely rich in iron-ore, sometimes porphyritic with crushed and shattered phenocrysts; and felsites with a minutely crystalline or lithoidal

base abundantly charged with calcite, or a more coarsely granular quartz-felspar mosaic, apparently greatly strained. It is, however, just possible that the last two fragments are of altered sedimentary rock.

Rocks similar to these, but with rather smaller grainsize, form the bulk of the Igneous Zone of the Middle Devonian, that sweeps northwards to Moore Creek. They resemble the "Bowling Alley breccias," of the earlier papers, with which they must assuredly be correlated (**16**, p.710-711). An example of these rocks, showing a more diverse composition than usual, is illustrated in Plate liii., fig. 6, which is from slide 1163, from a rock which accompanies the porphyritic spilites in Portion 48, Nemingha. It consists of single crystals and rock-fragments. The former include quartz, uralite, and acid felspar; the latter range from spilites resembling the base of the adjacent porphyritic spilite, to more crystalline trachytic spilites, fine- and medium-grained keratophyres; quartz-keratophyre; quartz-porphyrite; and a soda-granophyre. In addition, there is a fragment of radiolarian mudstone. There is practically no groundmass. The metamorphic effect of the granites, which are exposed within half a mile of here, is seen in the development of abundant little flakes of secondary biotite in the fragments of keratophyre.

Other rocks in this zone differ from this in the presence of fragments of dolerite, of more sedimentary rocks, and sometimes of limestone, or in the presence of crystals of augite or magnetite In others, again, more groundmass is present, generally finely divided quartz, and felspar, with more or less chlorite. These are only differences of degree; no distinct varieties of pyroclastic rock can be separated. In the most finely granular of these rocks, the fragments are usually merely portions of single crystals, or of very minutely crystalline keratophyre. They have often a more abundant base of comminuted quartz and felspar, and, while they are generally unstratified, bedding is at times very clearly marked. Some of the pyroclastic rocks contain very well preserved radiolaria(**10**). The felspar is usually albite. In one instance only has hypersthene been observed in these rocks. As a rule, the pre-

sence of stratification and of organic remains are the only means of distinguishing, in *hand-specimen or microscope-slide,* an interstratified from an intrusive tuff.

All along the margin of the granite, these rocks are found to be more or less altered. This metamorphism has been described in general terms in a previous paper(16), and very little additional information has been obtained from the present more detailed study. Generally, the effect has been to convert all the ferromagnesian minerals present into actinolite, which may be scattered all over the rock in secondary sheaf-like recrystallisations. The ilmenite becomes titanomorphite, and the plagioclase, clear albite, which may be more or less crystalloblastic. In more altered rocks, the felspar returns to andesine, which has been found in several instances, particularly in Portion 118, Nemingha. This accords with the behaviour of the spilitic rocks about the granites of Devonshire(27). Erdmannsdörfer concludes, from his study of the diabases about the granite of the Harz Mountains, that, whereas the presence of basic felspar is an index that the rock has suffered contact-metamorphism, types with acid felspar result from dynamic metamorphism(28, p.73); this conclusion cannot, however, be applied satisfactorily to the rocks of the Tamworth district.

The most altered forms of spilitic rocks are those in Sections 113 and 123, Nemingha. Macroscopically, they are very like the garnet-bearing contact-altered spilites of Walkhampton in Devonshire, which were described by Messrs. Dewey and Flett(27). They are banded dark green rocks, with long lenticular patches of quartz and felspar mosaic, probably representing former felspar-phenocrysts, and long bands of epidote and brown garnet, together with a little secondary acid felspar. The dark base consists of very finely matted chlorite and actinolite, while there are also streaks of secondary magnetite. It is not clear whether these are altered vesicular, porphyritic spilites, or pyroclastic rocks. The former is the more probable. Adjacent to these, is the amphibolite (altered dolerite) described above.

Other types of rock occur, of which a few examples will suffice. A rock (1134), which occurs in Portion 173, Tamworth, is an

altered breccia, made up of many differing portions, each uniform within itself. The more finely granular fragments consist of small short prisms of hornblende with a roughly parallel arrangement, in a groundmass of small, equant, untwinned grains of quartz, and (probably) andesine; occasionally, there are large, irregular plates of an indeterminable felspar. Surrounding each such fragment is a zone of larger crystals of hornblende, among which are frequently small patches of fresh, new-formed, colourless pyroxene, making irregular poikiloblastic plates. These have very oblique extinction, and a large optic axial angle. Rarely there are also poikiloblasts of hornblende. In the irregular groundmass between the fragments, there are also irregular prismoids of hornblende, granular and poikiloblastic secondary augite, poikiloblastic, dusty, twinned plagioclase, and abundant, usually untwinned oligoclase-andesine(?) in the matrix. Rarely, also, there are poikiloblasts of quartz that are quite free from strain-effects. Magnetite is scattered about.

Slide 1137, from the same locality, differs from 1134 in the presence of large porphyroblasts of andesine. The secondary augite at times shows a sieve-structure, but more usually forms solid grains, or scattered granules. Erdmannsdörfer has described the development of secondary enstatite in the altered diabases by the granite of the Harz(**28**, pp.17-19). The pyroxene in the rocks just described, though it is augite, seems also to be secondary; it is certainly not residual, and as it occurs only in rocks quite close to the granite, it is probably developed under the effects of contact-metamorphism. Erdmannsdörfer observes that the degree of metamorphism necessary to produce secondary pyroxene is greater than that necessary for the change of augite into fibrous amphibole(**28**, p.37); the present rocks seem to exemplify this conclusion.

In the altered limestone of Seven-Mile Creek, is a green felspathic rock (1372), which is probably an altered pyroclastic inclusion. It consist of large poikiloblastic grains of andesine, dotted with small grains of diopside, here and there aggregated into dense masses. Scattered about there is also sphene in irregu-

lar grains. A small amount of quartz occurs with the felspar, but iron-ores are not developed.

A very special form of pyroclastic rock is the agglomerate which occurs in Portion 162, Nemingha. As described above, this rock contains a number of rounded pebbles of igneous rock in a tuffaceous matrix. Though several types of rock appear to be represented among the pebbles on macroscopic examination, the miscroscope shows them to be mostly of one type in different stages of alteration. They are porphyrites, with phenocrysts of plagioclase, more or less decomposed, slightly zoned, and, for the most part, determinable as oligoclase. In some of these, the former zoning is strongly marked by the presence of kaolin or dusty matter, though optical tests show the crystal to be of uniform acid composition (cf. 29, p723). Augite also forms phenocrysts, but is more or less chloritised, and has a strongly marked outer margin of magnetite. There are smaller phenocrysts of magnetite, and corroded quartz, lying in a very fine-grained felsitic base. In addition, there is a porphyritic spilite, with phenocrysts of albite, in a pilotaxitic to subvariolitic groundmass of albite-laths, with chlorite, ilmenite, magnetite, and titanomorphite. Sometimes there are vesicles filled with calcite. One of these rocks is very similar to the spilite of Tintinhull, or of the Eastern Series. Another rock (1355) has a rhyolitic appearance, but is quite holocrystalline, and very finely granular. Its composition is that of a magnetite-keratophyre. There are idiomorphic or slightly corroded phenocrysts of acid felspar, and a few large accretions of minutely granular magnetite, and glomero-porphyritic quartz-felspar aggregates. The groundmass is made up of trachytic microlites of felspar, dotted with dusty magnetite, and interspersed with rounded felspar-crystals, which are not really spherulites, as their appearance suggests. These are arranged in bands, and thus give the rhyolitic appearance to the rock. The matrix of this rock is composed of crystals and fragments apparently derived from the porphyrites, which form the most abundant inclusions.

The pyroclastic rocks in the Upper Middle Devonian Series are similar to those in the Lower Middle Devonian, but are generally

more finely granular. The chief distinction, however, lies in the greater abundance of quartz and acid felspar in the newer rocks, fragments of cryptocrystalline and trachytic keratophyre being very common. In addition to this, there is an abundance of purely keratophyric material, which forms the white interlaminations in the claystones; these vary in thickness from some yards down to fractions of a millimetre. Sometimes they have a flat lower side when they have fallen on to partially consolidated clay, or the underside may be indented where the falling grains sank into soft silt. The upper side is quite irregular in both cases (see Plate liii., fig. 7). Such interstratified tuffs may contain radiolaria or plant stems. Intrusions of keratophyric tuff into the sediments are frequently observable under the microscope, a particularly clear instance being that shown in Plate liii., fig. 8. Fig. 9 of the same plate illustrates a clearly clastic rock, which is similar in all respects to the intrusive material in the specimen shown in Fig.8.

The general character of the Upper Middle Devonian and Upper Devonian pyroclastic rocks has been described thus:—"At some depth below the surface the colour of the tuff is greenish-grey, weathering to yellowish-brown or lighter grey at the surface, and thus contrasting strongly with the darker claystones. A chemical analysis of the tuff will be found on p.602. Mr. Card describes them as felsite-tuffs, with numerous fragments of cryptocrystalline felsite (Keratophyre, W.N.B.) entangled in the holocrystalline or microcrystalline groundmass. The latter is composed of broken or corroded crystals of plagioclase, orthoclase, quartz, and augite, with occasionally hornblende, and rarely sphene" (titanomorphite, W.N.B.). "Small crystals of iron pyrites are numerous and grains of titaniferous iron sometimes occur; small and large inclusions of radiolarian rocks abound."(9). The fragments of radiolarian rock in the tuff are often very rounded (see Text-fig. 10), and there is some alteration of the tuff about them. Numerous instances occur in which the inclusion is ringed around by a pinkish-white zone, which is very distinct macroscopically. Under the micro-

scope, however, nothing definite can be learnt as to its nature, and frequently it is not recognisable except in hand-specimen. At other times, there appears to be a slightly greater amount of kaolinisation, and the development of a little prehnite. It is evidently due to some radial diffusion, but does not appear to be connected with any process of albitisation. Prehnite is quite frequently developed in tuffs in patches that are not directly associated with cherty inclusions. So far as can be ascertained, the felspar in these pyroclastic rocks is almost entirely acid; no grain has been noted, of which the refractive index is greater than that of Canada balsam. The analysis (B., p 602) does not indicate any great amount of soda, and the composition of the felspar calculated therefrom is that of labradorite. The entry of alumina into various decomposition-products, probably accounts for the difference between the calculated and observed compositions of the felspar.

Limestones.

The macroscopic features of the limestones of this district have already been described. The following analyses illustrate their chemical composition. These were made by the chemists of the Geological Survey, for a memoir on the limestones of New South Wales, now being prepared by Messrs. J. E. Carne and L. J. Jones. The writer is much indebted to Mr. Carne for his kind permission to use them. Assays 1645-6 were specially made by Mr. Mingaye from specimens chosen by the author.

Assay No. ...	1146	1147	1394	1145	1148	1149
$CaCO_3$ ..	92·77	93·07	98·85	98·70	96·76	92·82
$MgCO_3$ ...	0·89	0·75	0·42	0·25	0·71	0·69
$MnCO_3$ ..	0·16	0·14	0·04	0·02	0 04	0·06
Fe,Al_2O_3 ...	0·42	0·40	0·22	0·19	0·33	0·28
Gangue ..	5·98	5·72	0·64	1·20	1·88	5·72
	100·22	100·08	100·17	100·36	99·72	99·57

Assay.	$CaCO_3$	$MgCO_3$	$FeCO_3$	$MnCO_3$	Fe_2O_3	Al_2O_3	Gangue	P_2O_5	H_2O	$BaCO_3$	*$SrCO_3$	Total.
1645	98·14	0·09	0·05	0·11	0·22	nil	0·98	0·03	0 58	nil	tr.	100·20
1646	97·42	0·04	0·04	0·04	0·44	0·09	1·62	0·02	0·36	nil	tr.	100·08

* Spectroscopic test.

These samples came from the following localities:—

Nemingha limestone.

1146. Portion 118, Nemingha.

1147. Portion 63, Nemingha (formerly Beedle's Freehold).

1645. White marble, Portion 134, Nemingha.

1646. Red marble, Portion 134, Nemingha, (known as the "Nemingha red marble").

Loomberah limestone(?).

1395. Portion 121, Nemingha.

Moore Creek limestone.

1145. Portion 41, Woolomol.

1148. Municipal Quarry, Spring Creek, Tamworth.

1149. Reserve 1472, Woolomol.

It will be seen that the rocks, as a whole, are very free from dolomitisation, and that the limestones of the Nemingha horizon differ from those of the Moore Creek horizon in the slightly greater content of iron, alumina, magnesia, and manganese. This is probably due to their association with igneous rocks, particularly the ferruginous brecciated keratophyres. It is clear that the intrusion of the ferruginous keratophyres was accompanied by the emission of iron-bearing solutions (**17**, pp.14-15). A red colour is a frequent feature of the limestones of this horizon.

The description of the radiolarian limestone given by the previous authors(**9, 10**) need not be supplemented here. Mr. Mingaye's analysis of this rock is cited below.

Around the margin of the granite, the limestones have suffered much alteration. This was briefly described in an earlier paper(**16**), and also in the paper by Messrs. David and Pittman(**9**). A number of additional slices made subsequently, have added but little to the information here given. The pyroxene developed seems, however, to be a green variety of diopside rather than omphacite. One new type of rock has been discovered in the northern, sharply bent anticline, in Seven-Mile Creek. It consists almost entirely of silky-white wollastonite. Its interstices contain diopside, calcite, and a doubly refracting garnet. In another sample, diopside and garnet predominate over the wollastonite, and the garnet forms aggregates, half an inch in diameter. A third rock contains a little scapolite.

Middle Devonian Cherts and Claystones.

The sedimentary rocks of the Middle Devonian Series have few features of petrological interest. The general characters were described by Messrs. David, Pittman, and Card(9), and the writer(16). Here and there, they are enriched with tuffaceous matter, where zones of larger grainsize composed of fragments of quartz, felspar, or cryptocrystalline felsite, are interstratified with the normal claystone, into which they gradually shade away. In none of the rocks which the writer has studied microscopically, has he been able to recognise the presence of minerals which ordinarily characterise contact-metamorphism, nor does it appear probable that they would be developed, if the intrusions of the pyroclastic material took place in the manner here described, which would involve an intrusion at a fairly low temperature.

Considerably altered rocks occur about the granite; the most intensely altered are those actually included in the granite in Portion 66, Tamworth. These have abundantly developed biotite, and are interleaved with narrow bands of pegmatite, and granite. A less altered type (1133) is a fine-grained quartz-schist, with minute, chloritised flakes of biotite, and fragments of orthoclase and andesine.

The chemical composition of the sedimentary rocks will be seen in the table herewith, of analyses by Mr. Mingaye(9).

Assay number ('97)...	1234	1236	1235	1233
SiO_2	91·06	80·50	67·87	18·05
Al_2O_3	3·79	9·57	15·25	3·49
Fe_2O_3	2·01	2·67	5·08	4·87
MgO	0·46	0·76	1·46	1·65
CaO	0·45	0·60	1·71	38·70
Na_2O	0·28	1·18	1·37	0·29
K_2O	0·84	1·68	2·21	0·44
H_2O	0·97	1·29	2·10	1·42
H_2O-	0·32	0·45	2·37	0·80
CO_2	—	—	abs.	30·15
P_2O_5	tr.	0·11	0·12	0·34
SO_3	0·35	tr.	tr.	tr.
FeS_2	—	—	—	0·24
MnO	tr.	tr.	tr.	tr.
Organic matter	tr.	0·86	—	tr.
	100·53	99·67	99·54	100·44

1234.	Radiolarian black chert.	The exact points at which these rocks were collected are not stated. They all came from the neighbourhood of the Tamworth Common.
1236.	Radiolarian cherty shale.	
1235.	Radiolarian shale.	
1233.	Radiolarian limestone	

Upper Devonian Baldwin Agglomerate.

Messrs. David and Pittman have pointed out that the matrix of the agglomerate occurring on Cleary's Hill, near Tamworth, is identical with the breccias of the Middle Devonian Series(9). The writer has shown that this is a part of the Baldwin Agglomerates, and that this similarity is a constant feature; indeed, the agglomerates may be described as an "exaggeration of the features of the breccias of the Tamworth Series," and when they take on a rather finer grainsize than usual, it is impossible to distinguish them from the Middle Devonian rocks. At certain points they are full of rounded boulders, which decrease in size as the strata are traced laterally. Each centre has about the same assortment of boulders, though differences occur. The boulders in the agglomerates at Cleary's Hill include the following:—Porphyritic dolerite, with phenocrysts of albite and augite, and a subvariolitic base; porphyritic spilite, with felspar-phenocrysts and minutely crystalline trachytic base; felspathic dolerite; porphyritic andesite, as described by Mr. Card(9, p.36), in which the augite has the peculiar brownish tint and appearance characteristic of the brecciated augite-porphyrite described above (p.598); with decreasing amount of ferromagnesian minerals, these dolerites pass into keratophyres, sometimes porphyritic, but with a beautifully trachytic base (a very common rock), or the base may be felsitic or cryptocrystalline; one example is orthophyric and has no phenocrysts. There is also a quartz-keratophyre, the phenocrysts of which are more or less corroded quartz and albite, and the cryptocrystalline base contains long patches of fibrous radiating felspar, and also fragments of magnetite-keratophyre. In addition, there are fragments of previously consolidated tuff, of limestone, and of chert. The matrix consists chiefly of fragments of felspar, often zoned andesine, but also albite, quartz, augite, ilmenite, and a still more minutely comminuted paste of these minerals, with calcite, chlorite, etc. The chemical composition of the matrix has been determined by Mr. White. (See C, p.602).

The agglomerate of Housefield's Hill, in the centre of the Parish of Woolomol, contains approximately the same variety of boulders. The peculiar strained quartz-keratophyre is found also as a dyke beside the hill. The waterworn appearance of the pebbles and boulders is especially marked in this locality.

Serpentines.

The majority of the serpentines seen are similar to the rocks described in the earlier paper(**16**), and do not call for any further comment. One specimen, however, from Portion 118, Parish of Nemingha, is of special interest. It is a typical example of a serpentine derived from diallage The chief constituent of the rock is antigorite, which in some places exhibits the "gitter-struktur" perfectly, but is more usually distributed rather irregularly, or grouped into radiating masses. Some residual diallage is present, into which the antigorite cuts sharply, either as irregularly placed blades, or in lines parallel to a cleavage. The last remnants of the diallage are cloudy grey matter. Small ribbon-like veins and irregular patches of fibrous anthophyllite(?) are also present, sometimes stained brown and matted, but never notably pleochroic. The anthophyllite-fibres may stretch across the whole width of the vein, or may grow out unevenly on either side of a narrow crevice. Very irregularly shaped masses of magnetite are scattered about.

Associated with the serpentine is a little gabbro, which has also been described; it is remarkable for the replacement of its felspar by zoisite. One specimen contained olivine and hypersthene, two minerals which are rarely seen in the gabbros in the Great Serpentine Belt. (See **16**, pp.683-4).

Dykes of Dolerite in the Serpentine.

A number of these have been studied, and found to correspond exactly with those described from the north side of Chrome Hill, Bowling Alley Point, of which an analysis has been made (**17**, p.139). According to the extent of the development of brown hornblende, the rocks may be classed as dolerites, with little hornblende, and proterobases, in which it is more abundant. The hornblende, however, is always subordinate to the augite,

and frequently surrounds this mineral. The felspar is difficult of determination, but it seems to be sometimes oligoclase, sometimes andesine. The ilmenite is usually represented by titanomorphite. Some sheared varieties of dolerite occur in which saussuritised felspar alternates with streaks of tremolite.

Granite.

The granite has been described by Mr. Card as follows :—
"6665. Moonbi, close to the railway station. Not conspicuously porphyritic. Sphene readily visible. The quartz is crowded with cavities. Hornblende and magnetite are intimately associated in places, and, together with felspar, give rise by segregation to basic patches. Orthoclase and plagioclase are present. The plagioclase may contain many foreign inclusions, and may show good composition zoning; it appears to be a variety of oligoclase. Sphene is conspicuous, and shows some intergrowth with hornblende.

3728. Moonbi Tobacco Farm. This type is decidedly dioritic, and differs much from that above described. It is non-porphyritic. Sphene is abundant and can be readily obtained (sometimes in well formed crystals) by washing the crumbling material under water. Under the microscope, one of the dominant minerals is hornblende; biotite is scarce. The hornblende is deep green in colour for the most part. It is more or less automorphic, and well cleaved. Sphene is plentiful. There is a little quartz, and practically no plagioclase. Orthoclase is perhaps somewhat larger in quantity than the combined ferromagnesian silicates. The leucocratic constituents are plentifully traversed by highly elongated, colourless, transparent rods. As a handspecimen, this rock would be classed as a quartz-syenite." (**12**).

Sections examined by the writer show similar features to those recorded above, but, in general, orthoclase does not seem to be so abundant as there indicated.

The numerous dykes of pegmatite and aplite have not been subjected to microscopical examination.

The more basic dykes show interesting features; the following may be recorded :—

1302. A dark vein in granite in Portion 114, Nemingha. This consists of a fabric of short laths, and less regular grains of plagioclase and orthoclase with interstitial quartz. A few corroded xenocrysts of the two felspars and quartz are also present; the last is very distinct from the groundmass, and is surrounded by a reaction-ring. In addition, there are abundant fresh grains of augite and platy ilmenite. The rock may be termed a micro-monzonite, or monzonite-aplite.

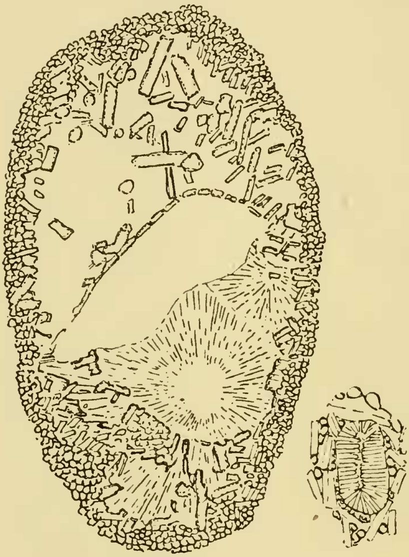
1308. A vein in Portion 145, Nemingha. This is also a micro-monzonite, but is of a different character. The felspars are larger, more irregular, and partially interlocking. The augite has been replaced by hornblende, and some sphene is present.

1174. A vein in the granite in Portion 73, Moonbi. This is very similar to 1308, but differs in presence of a groundmass of small felspar-laths, and small crystals of hornblende, and rarely a flake of biotite. The felspar seems to be chiefly plagioclase. The rock may be termed a micro-diorite or a diorite-aplite.

1175. A vein in the granite in Portion 139, Moonbi. This is the most unusual rock. It is a minette with spheroidal inclusions, rather different from the "Kugelminette" of the Odenwald and elsewhere(**30**). The rock consists of crystals of brown, almost uniaxial biotite in idiomorphic plates, idiomorphic augite, and magnetite, in a finely granular, felsitic matrix, dotted with minute crystals of magnetite, and a few minute prisms of apatite. The spherules are about 2-3 mm. in diameter. They consist of fibrous radiating felspar, with a little quartz in the central parts. Included in these are large crystals of diopside and biotite, which, in one instance, are in completely parallel intergrowth with each other. A little magnetite is dotted about. There is no bounding zone of coloured minerals marking the outline of the spherules. There are, in addition, druses with an angular, irregular outline surrounded by a "fence" of diopside-prisms, directed radially inwards, followed within by an irregular zone of untwinned felspar, with a central quartz-felspar mosaic. The inner zone is dotted with diopside and magnetite.

Tertiary Basalt.

The basalt is extremely fresh. It consists of small laths of labradorite, slightly zoned, granules of augite, large prismoid, but not idiomorphic grains of olivine, and small irregular grains and aggregates of ilmenite. There is a vesicle about 2 mm. in in diameter, the structure of which is shown in Text-fig.15. All round the vesicle is a thick zone of minutely granular augite,



A B

Fig. 15.—A. Amygdule in Tertiary basalt(1164). Upper and middle portion opal, lower natrolite. The first and last of these contain prisms of augite. B. Spherule of augite-prisms in the same rock as A.

but within are comparatively large idiomorphic prisms of augite, of the same character as that in the groundmass of the rock, but lying more or less isolated in a matrix of opal and natrolite. The prisms are particularly well formed in the opal. The determination of this mineral is rendered certain by the very clear evidence of Becke's line, which shows that the colourless isotropic mineral has a distinctly lower refractive index than the natrolite. It is quite clear, and crossed by irregular cracks, without any sign of cleavage, such as analcite might show. There can be

little doubt that the vesicle was filled with magmatic water. It would seem that the jelly-like mother-liquor in the vesicles permitted the growth of well formed prisms of augite, which were pushed aside by the growing and mutually interfering spherical masses of natrolite and opal, in the outer portion of which the augites become imbedded. The growth of large idiomorphic crystals of ferromagnesian minerals in the concentrations of the residual magmatic water is analogous in some respects to the formation of barkevicite in the analcitic lugarites of the Glasgow district described by Tyrrell(**31**). It is also interesting as affording a good instance of the primary nature of a zeolite, upon which subject a considerable literature has accumulated in recent years. [See *e.g.*, Mr. Harker's Presidential Address(**32**), and the article (and bibliography) by Koenigsberger(**33**)]. Beside the vesicles, there are small veins and irregular patches of opal and natrolite, and a little radiating aggregate of augite illustrated in Text-fig.15B. In addition to these, there are also present a xenolith of olivine, augite, anorthite, and picotite, and isolated grains of the same minerals. Such xenoliths and xenocrysts are commonly present in the Tertiary and Recent basalts throughout the world.

Summary.

The main results of the present work may be stated thus. A more detailed map has been made of the Tamworth district, than that given by the previous authors who studied the district, and the subdivision of the Devonian Series instituted elsewhere in the Serpentine Belt has been applied, with amplifications, to this district. The result has been a general confirmation of the earlier work, with some modification in the details. The history of the area was apparently as follows. In Devonian times, a series of radiolarian claystones was deposited on a steadily sinking sea-floor, which was maintained at a fairly shallow depth. During this period, there were great developments of volcanic activity, producing large amounts of pyroclastic matter, building masses of tuff and agglomerate, which, here and there, may have risen above the surface of the sea, as small, short-lived islands. There were two main

periods of activity, the first of which was also marked by the intrusion of massive and brecciated spilites, dolerites, and keratophyres. Peculiar types of intrusive tuffs were constantly developed, and their probable mode of origin is here discussed. At two or three epochs, limestones were formed, and the fossil-content of these is sufficiently varied to permit of their distinction on palæontological grounds. The total thickness of the series cannot be exactly determined, owing to the presence of an indefinite amount of faulting. An apparent thickness of over 12,000 feet of strata are of Middle and Upper Devonian age. Folding and faulting occurred probably in Carboniferous times. The movements were most pronounced along an axis running N.N.W.-S.S.E., but there is clear evidence of less important movements along a N.E.-S.W. axis. The folding was followed by the intrusion of peridotite, succeeded by that of a mass of granite, which produced interesting contact-metamorphism of the tuffs and limestones. No further events are recorded until the eruption of a small amount of basalt, probably during the Tertiary period. The discussion of the physiography is reserved for a future occasion.

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EXPLANATION OF PLATES XLIX.-LIII.

Plate xlix.

Topographical Map of the Tamworth District, plotted from a plane-table survey, with contour-lines based on aneroid observations.

Plate l.

Geological Map of the Tamworth District.

Plate li.

Geological Sections along certain lines through the Tamworth District. The vertical and horizontal scale is the same.

Plate lii.

Fig. 1.—Sheared keratophyre from the Eastern Series (1305); × 16.
Fig. 2.—Brecciated hypocrystalline augite-porphyrite (1303); × 13.

Fig.3.—Magnetite-keratophyre with secondarily introduced magnetite (1148); ×13.

Fig.4.—Magnetite-keratophyre-breccia with inclusions of dolerite (1122); ×13.

Fig.5.—Breccia of various types of keratophyre, dolerite, spilite, and chert (1355); ×13.

Plate liii.

Fig.6.—Similar to Plate lii., fig.5, but with large grains of quartz (1163); ×17.

Fig.7.—Crystals of felspar and fragments of microcryptocrystalline keratophyre in radiolarian mudstone (N.S.W.G.S. 627); ×17.

Fig.8.—Intrusion of felspathic tuff into radiolarian mudstone. The clear, colourless casts of radiolaria can be seen in abundance (N.S.W. Geol. Survey, 1190); ×2.

Fig. 9.—Felspathic tuff of the same character as that in Fig.8; ×16 (approx.). Polarised light.

Fig.10,—Intrusion of breccia into banded tuffaceous mudstone; one-half natural size. See Text-fig.5.

Corrigenda to Part iv. (this Volume), pp.121-170.

Page 127.—*for* "Text-fig.1. Spilite intrusive into radolarian clay." *read*, "Spilite intermingled with chert."

Page 143, line 12.—*for* "fig.3", *read* "fig.4".

Page 160, lines 17-18.—*for* "From the nature of the case", *read* "For topographical reasons (see Map (1), Plate xxii.)"

Postscript (*added October* 28*th*, 1915).—M. Giraud's description of the peperites, (basaltic tuff-breccias) of the Auvergne, has come under the writer's notice while the above was in the press (Bull. des Services de la Carte Géologique de la France, No. 87, 1902, pp. 299-367). The author reviews an extensive literature, and concurs with M. Michel Levy in considering that the peperites are instrusive into the Oligocene marls in the Limagne. They form selvedges to basalt-dykes, developed where the dykes traverse weak structures, such as marls, but not where they invade strong structures, such as granite or limestone. Contact-effects are visible above as well as below the peperites. Where the overlying strata are sufficiently thin, the peperites broke through to the surface, and were deposited in water; such sedimentary peperites contain

organic remains, *Helix,* etc. M. Michel Levy thought the conversion of the basalt-magma into fragmental material, was perhaps due to the rapid escape of water from the magma, in regions where the containing walls of the dyke offered little resistance. It is often difficult to draw any line between the solid basalt and the marginal breccia, which has been thrust laterally into the weak structures. Sir A. Geikie remarks: "The material of the peperites has undoubtedly here and there filled up the volcanic vents, and has been injected in veins and dykes around their margins. But the main mass of the material was ejected from the vents, and falling, as volcanic dust and sand . . . became interleaved with the contemporaneous sediments" (Textbook of Geology, 4th ed., p.1255, footnote). It seems reasonable to suppose that, if loose marls below solid limestones, permit a magma to break up into pyroclastic material, such an action will be even more favoured in loosely consolidated sediments without a compact covering layer. To this extent, the French peperites help us to understand the features of the Tamworth tuffs. One cannot, however, decide to what extent the pulverisation of the consolidating magma was brought about by the escape of magmatic water, or by the constant forward movement of the magma, or by the strains set up, as in a Prince Rupert drop, by the rapid chilling of the melt. The general absence of recognisable points of eruption makes it also impossible to estimate the distance to which the intrusive tuffs have been thrust laterally into the sediments. But though clearly intrusive tuffs have been found at many points, it is probable that the fossiliferous tuffs and breccias deposited in the normal fashion constitute the greater part of the pyroclastic rocks in the Great Serpentine Belt.

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